UNIVERSITY OF ALBERTA LIBRARY
0 0004 8499 768

EXPLORING THE WORLD OF SCIENCE

CURRICULUM

SUMMER SCHOOL FOR TEACHERS

Ex libris
universitatis
albertaensis

UNIVERSITY OF ALBERTA
QUAECUMQUE VERA

2

SUMMER SCHOOL FOR TEACHERS

Digitized by the Internet Archive
in 2018 with funding from
University of Alberta Libraries

https://archive.org/details/exploringworldof00lake

SUMMER SCHOOL FOR TEACHERS

EXPLORING THE WORLD OF SCIENCE

BY

CHARLES H. LAKE
SUPERINTENDENT OF PUBLIC SCHOOLS AND FORMERLY PRINCIPAL OF EAST TECHNICAL HIGH SCHOOL, CLEVELAND

HENRY P. HARLEY
SUPERVISING TEACHER OF SCIENCE, FAIRMOUNT JUNIOR HIGH TRAINING SCHOOL, CLEVELAND

LOUIS E. WELTON
ASSISTANT PRINCIPAL AND FORMERLY HEAD OF SCIENCE DEPARTMENT, JOHN HAY HIGH SCHOOL CLEVELAND

Drawings by Adrian J. Iorio and Barry Bart

SILVER BURDETT COMPANY

NEW YORK . BOSTON . CHICAGO
SAN FRANCISCO

Copyright, 1934, 1939
By SILVER BURDETT COMPANY

This copyright makes it illegal to copy or to reproduce any part of the contents of this book without written permission from the publisher, except in the case of a reviewer who wishes to quote passages in connection with his review.

LIBRARY OF THE UNIVERSITY
OF ALBERTA

Printed in the United States of America

Educ

Q
161
.L19

PREFACE

The subject matter of this book was selected after a thorough investigation of the material which experience has proved to be most valuable in the study of General Science, and which is within the comprehension of the pupil. The selection of the material was based primarily upon the student's immediate life interests, the educational value of the material to him, and its probable use in adult life. The selection was governed by the long and varied experience of the authors as teachers of science and their first-hand knowledge of pupils of adolescent age. The material chosen was organized into a unit of science which is complete, regardless of whether the pupil ends his school study of the subject with this course or whether he continues with more work in science.

The text is organized on the unit basis and is composed of sixteen units. The material for each unit centers around one of the major problems of the pupil's environment. Each unit is subdivided into problems. The techniques employed in the solution of the problems are designed to aid the pupil in the formation of habits of scientific procedure. The subject matter is therefore presented as a means whereby the pupil may formulate sound conclusions in the process of solving problems and not for the sole purpose of presenting facts to be learned even though they may be important in themselves. The problems proposed approximate life situations, and in their solution the pupil is gaining knowledge and learning to adjust himself to his scientific environment. Each problem is presented with the idea that the student will arrive at the relevant scientific principle or generalization.

The "Exploring" stories at the beginning of each unit and "Do You Know" questions at the beginning of each chapter are designed to lead the pupil naturally into the study of the unit. An examination of ~~this~~ material will show that it connects the life experiences of the pupil with the new material of the unit in a

120684

natural sequence. The discussion of the "Do You Know" questions will raise other questions, the answers to which may be delayed until the unit is studied. This motivation will lead to eager mental and motor activity in the solution of the problems of the unit. Scientific principles and generalizations developed in this way become part of the realized experience of the pupil.

There is an abundance of material to provide for individual differences. The "Special Problems" in the body of the unit furnish extra work for the superior pupil. The statement of scientific principles in sentence form affords an excellent opportunity for practice in reflective thinking. The "Problems and Projects" at the end of each unit suggest activities involving construction, observation, and research at the level of the pupil's ability. These activities together with special notebook work give ample opportunity for pupils to exercise their initiative and creative ability to the fullest extent.

The list of technical words at the end of each chapter furnishes an opportunity for the pupil to acquire a scientific vocabulary. The acquisition of this vocabulary will enable a pupil to read scientific books and articles with a greater degree of understanding and appreciation. The significant technical terms throughout the text are printed in italics. The pupil should be encouraged to learn to spell and use each of these terms correctly.

At the end of each chapter is a group of statements of the objective test type which the pupil may use as a self-test. After he has completed his work on the chapter, the pupil should check his mastery of the material with these statements.

In the opinion of the authors the science notebook should be more like an informal science scrapbook than a formal notebook. There is such an abundance of experimental work presented that if a pupil were required to write a formal outline of each experiment performed he would have an endless task and probably his interest in science would be destroyed. On the other hand the pupil should be allowed to enjoy the motor and mental activity of the experiments and encouraged to concentrate his efforts upon comprehending the principle or generalization developed. Furthermore, he should be encouraged to seek everyday applications of the results of his experimental work in his reading and daily observations and to record these in his notebook. These may be pictures, clippings from articles, or statements of his own observations. If given a few helpful suggestions at the beginning of their science study and then allowed to develop their own initiative and ingenuity, pupils have been known to produce outstanding pieces of scientific work. A notebook of this kind shows the teacher the steady growth of the pupil in adjusting himself scientifically to his environment.

The authors wish to acknowledge their obligation to many scientific and educational sources and in a personal way to those teachers of science who have given them encouragement during the preparation of the manuscript.

Charles H. Lake
Henry P. Harley
Louis E. Welton

PREFACE TO THE 1939 EDITION

Since the publication of the first edition of EXPLORING THE WORLD OF SCIENCE, new discoveries and new uses of science have been developed which affect the everyday life of pupils. In this edition, in order to bring these developments to pupils, more than sixty-five illustrations have been revised or changed and subject matter has been added or revised concerning air conditioning, conservation of water and soil, flood control, dams, waterpower and its uses, prevention of accidents (safety), artificial lighting, transportation, communication, weather, weather forecasting, building materials, vitamins, minerals in food, and other topics.

Furthermore, a glossary has been added and the index has been extended. Both of these will be of assistance to pupils who are in search for materials to be used in solving problems and will facilitate the teachers' work in making assignments to care for individual differences of pupils.

In general, then, it has been our purpose in revising EXPLORING THE WORLD OF SCIENCE to bring to the pupil some of the new discoveries in science, new uses of science, how these affect his everyday life; and to make the book fit the needs of pupils and teachers in the modern school.

The Authors

CONTENTS

Page
FRONTISPIECE x
Chapter
I. HOW HAS SCIENCE REMADE THE WORLD? 1

UNIT I. WHAT IS THE ATMOSPHERE AND HOW DOES IT AFFECT OUR DAILY LIVES?

II. DO WE LIVE AT THE BOTTOM OF A GREAT OCEAN? . 11
III. HOW ARE ATMOSPHERIC PRESSURE AND COMPRESSED AIR USED TO DO WORK? 24
IV. WHAT IS THE ATMOSPHERE MADE OF? 38

UNIT II. WHAT IS SOUND AND WHAT USE DOES MAN MAKE OF IT?

V. HOW ARE SOUND AND MUSIC PRODUCED AND HEARD? 51

UNIT III. WHAT IS WATER AND WHAT USE DOES MAN MAKE OF IT?

VI. WHY IS A SUPPLY OF PURE WATER NEEDED FOR OUR HOMES? 69
VII. OF WHAT IS WATER COMPOSED AND WHAT ARE SOME OF ITS PROPERTIES? 84
VIII. HOW DOES MAN MAKE USE OF WATER PRESSURE IN INDUSTRY AND TRANSPORTATION? 99

UNIT IV. HOW DO WEATHER AND CLIMATE AFFECT OUR LIVES?

IX. HOW DO CLIMATE AND CHANGES IN WEATHER AFFECT OUR DAILY LIVES? 116
X. WHAT MAKES THE WEATHER CHANGE? 126

UNIT V. WHAT IS THE UNIVERSE AND WHAT IS THE PLACE OF OUR EARTH IN IT?

XI. HOW IS THE EARTH RELATED TO THE SUN AND THE OTHER STARS? 157

Chapter Page
XII. HOW DOES MAN MEASURE TIME AND DETERMINE THE LOCATION OF A PLACE ON THE EARTH? 190

UNIT VI. WHAT IS SOIL AND HOW IS IT FORMED?

XIII. OF WHAT IS THE CRUST OF THE EARTH MADE AND HOW IS IT CHANGING? 207
XIV. WHAT IS SOIL AND HOW DOES MAN PREPARE IT FOR GROWING USEFUL PLANTS? 228

UNIT VII. WHAT SIMPLE BUILDING MATERIAL MAKES UP THE UNIVERSE?

XV. OF WHAT MATERIALS IS THE UNIVERSE COMPOSED? 249

UNIT VIII. WHAT ARE THE FORCES OF NATURE AND WHAT USE DOES MAN MAKE OF THEM?

XVI. WHAT ARE SOME OF THE FORCES OF NATURE? . . . 279
XVII. HOW ARE THE FORCES OF NATURE USED TO DO WORK? 293

UNIT IX. HOW HAVE MACHINES MADE THE WORK OF MAN EASIER?

XVIII. HOW DOES MAN USE MACHINES TO DO WORK? . . . 310

UNIT X. HOW DOES MAN SECURE HEAT FOR HIS DAILY NEEDS?

XIX. FROM WHAT SOURCES DOES MAN SECURE HEAT? . . 337
XX. HOW DOES HEAT SERVE MAN? 355

UNIT XI. WHAT IS LIGHT AND HOW DOES MAN MAKE USE OF IT?

XXI. HOW DOES MAN PROVIDE LIGHT FOR HIS DAILY WORK AND PLAY? 387
XXII. HOW DOES LIGHT GIVE US COLOR AND PRODUCE THE SENSATION OF SIGHT? 403

UNIT XII. HOW HAS ELECTRICITY BECOME MAN'S GREATEST SERVANT?

XXIII. WHAT IS ELECTRICITY AND HOW IS IT GENERATED? 428

Chapter Page
XXIV. HOW IS ELECTRICITY USED IN HOME AND INDUSTRY? 461
XXV. HOW IS ELECTRICITY USED IN COMMUNICATION AND TRANSPORTATION? 478

UNIT XIII. HOW DO PLANTS MAKE FOOD AND STORE UP ENERGY?

XXVI. HOW DO PLANTS GROW AND STORE UP FOOD? . . . 507
XXVII. WHAT MATERIALS DOES MAN GET FROM PLANTS? . . 537
XXVIII. WHAT ARE SOME OF THE LOWER FORMS OF PLANTS AND WHY IS IT NECESSARY TO PROTECT USEFUL PLANTS? 549

UNIT XIV. OF WHAT USE ARE ANIMALS TO MAN?

XXIX. WHAT ARE THE KINDS OF ANIMALS AND HOW ARE THEY USEFUL TO MAN? 570

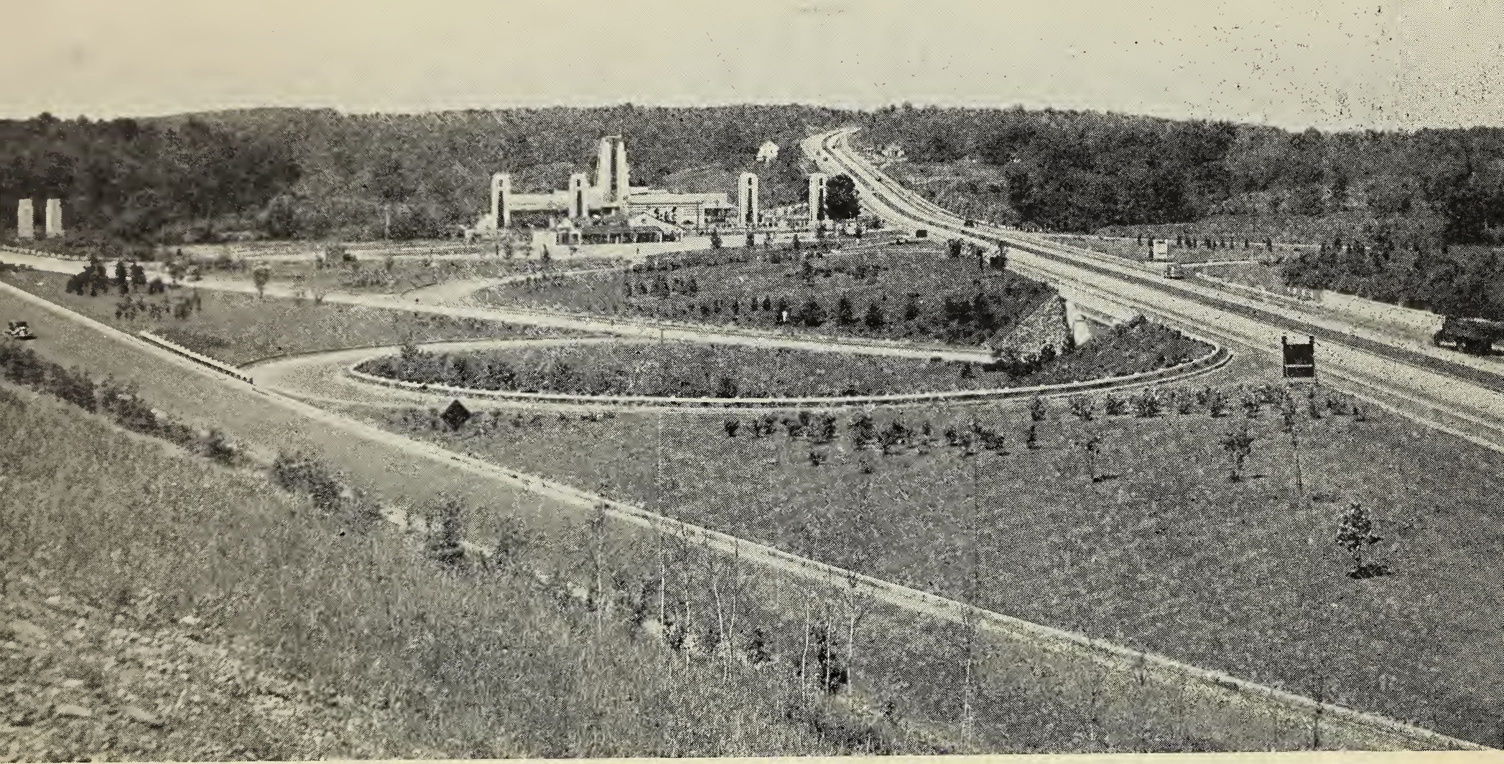
UNIT XV. HOW IS IT POSSIBLE TO BUILD A HEALTHY BODY?

XXX. IS A WELL-PLANNED DIET NECESSARY TO BUILD AND MAINTAIN A HEALTHY BODY? 607
XXXI. HOW DO THE ORGANS OF THE BODY COOPERATE IN MAINTAINING HEALTH? 630

UNIT XVI. HOW CAN YOU KEEP YOUR BODY HEALTHY?

XXXII. HOW CAN WE PROTECT OUR BODIES FROM DISEASE? 655
XXXIII. HOW CAN WE PROTECT OUR BODIES FROM HARMFUL GERMS? 668

GLOSSARY 683
INDEX 697



Courtesy Roadside Development Division of Massachusetts Dept. Pub. Works

Fig. 1. Scientifically planned highways help to reduce accidents on our highways. Explain how. Do you see any bill boards?

CHAPTER I

HOW HAS SCIENCE REMADE THE WORLD?

Problem: How Did Science Begin?

As long as man has lived on the earth, he has been trying to answer the questions which came to him from his everyday life. In ancient times, man was puzzled by the rising and setting of the sun and its daily journey across the sky; he was filled with awe by the stars on clear and cloudless nights. The change of seasons filled him with wonder. He could not understand why rocks tumbled down a mountain side, or why streams and rivers rushed swiftly to the sea. He supposed that sickness was caused by an evil spirit in the body which could be driven out by charms or by the magic of a witch doctor.

Men of this time made rough spear heads and ax heads to kill small animals and to protect themselves from wild beasts; they learned to use poles to raise large stones and lift heavy logs, and to make crude implements with which to cultivate the soil. They discovered how to use fire to cook their food, to make metal tools, and to protect themselves from cold and from fierce animals.

As civilization progressed, some men began to seek answers to questions about their environment. They began to observe phenomena carefully, to study nature systematically, and to use their crude tools to help them in experimentation. In this way science began, and these men were the first scientists.

Problem: How Do Scientists Work?

One day a small boy, playing beside a stream, noticed a thin, black creature swimming in the water. After watching it the boy ran to tell his father what he had discovered, and to ask what the animal was. His father replied that the squirming animal was a young eel and that it had grown from a horse hair that had fallen into the water. Do you believe the explanation a true one?

This explanation of a phenomenon of nature, and others even more fantastic, have been handed down for hundreds of years. Perhaps you have heard that: a crocodile weeps when it has eaten a man, a hedgehog sticks grapes upon its quills and carries them home to its children, a crab waits until an oyster opens its shell and then puts a stone in the opening so that it may eat the oyster, a buried crab becomes a scorpion, and barnacles change into geese.

It is easy to see how such explanations were passed down from one generation to the next, but not so easy to see how they got started. They are due, in part, to inaccurate observations or the lack of observation. In the beginning someone did not take the time and pains to discover the real facts, and perhaps, being eager to appear wise, advanced a theory to explain what he had seen. His friends believed him and passed the story along as true.

How two scientists discovered the truth about the origin of young eels. The story of how two Italian scientists, Grassi and Calandruccio, discovered how eels develop will help you to understand how scientists arrive at truth. These two men by careful and accurate observation showed how eels develop. They observed that at a certain time of year full-grown eels swam down rivers to the sea and at other times young eels swam up rivers from the sea. By continuing their observations of full-grown eels in the sea they learned that they laid eggs which developed into colorless, transparent creatures (baby eels). Observation of the baby eels showed that they grew to a certain size and then stopped eating. During this resting stage their bodies shrank and took on the form of young eels that soon began their long journey from the sea up a river. It was one of these that the boy saw.

The fact that eels lay their eggs so far from rivers where they were most frequently seen helps to account for the false explanation that horse hairs turn into eels. Young eels and full-grown eels had been seen, but not baby eels. Consequently an explanation or a theory was advanced to explain what was not known. So you see how false explanations or theories may develop because of failure to obtain enough facts upon which to arrive at truth.

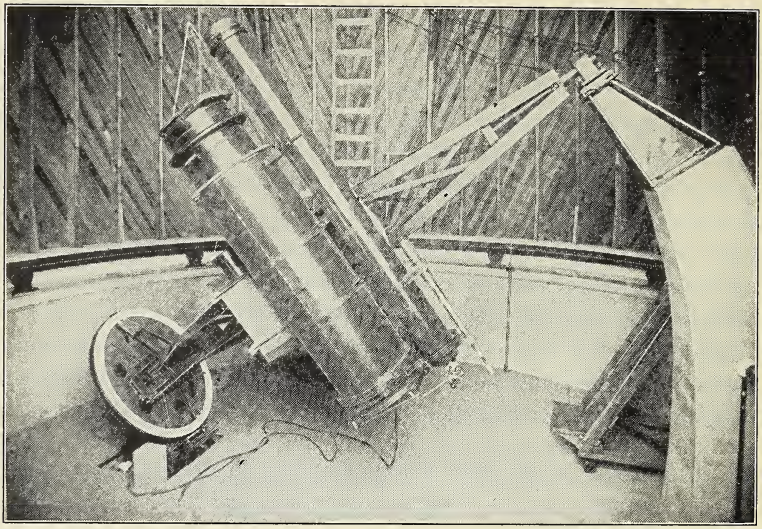
How a scientist works. When the inquisitive mind of a scientist is confronted with a problem, he uses the scientific method. This method is well illustrated by the way in which Pascal (page 17) discovered whether a change in altitude causes a change in atmospheric pressure. Pascal advanced the theory that the pressure of the atmosphere must decrease as the height above sea level increases. He tested the truth of his theory in the way described on page 18. His experiment showed that his theory was correct. He then asked his brother-in-law to verify his theory. His experiment also confirmed Pascal's theory. In consequence Pascal decided that his theory was a sound one. After a theory has been verified many times and has been accepted widely by scientists, it is called a law. A scientist is not satisfied with only one or two experiments which test the truth of his theory. Sometimes thousands of experiments are performed before a theory is accepted generally.

PROBLEM: HOW DID SOME OF THE SCIENCES BEGIN?

Some early observers. In the days of ancient Egypt, observers of Nile floods noticed that each year the floods came at the beginning of the summer season. Over a period of years they noted the point on the horizon at which the sun rose on the day the Nile began to rise. Finally they agreed that this day should mark the end of one year and the beginning of the next. Thus the Egyptians developed a rather accurate calendar because men had made careful observations of a phenomenon of nature.

The Babylonians also developed a calendar. In their observations of the movements of the moon they noticed that it passed through its four phases in about twenty-eight days. This period of time they called a month. They divided the month into four periods, according to the four phases of the moon; we still use their seven-day week. A year, they decided, should consist of twelve months. How many days would there be in twelve twenty-eight-day months? Although the Babylonian calendar was inaccurate it served a very useful purpose.

A baffling problem. Early astronomers encountered a problem which baffled them greatly. As they watched the heavenly bodies, it seemed to them that the earth was the center of the universe and that the sun, stars, and moon moved across the sky from east to west.



Courtesy Lowell Observatory

Fig. 2. The Lawrence Lowell telescope at Lowell Observatory, Flagstaff, Arizona, which was used in 1930 in the discovery of Pluto, the ninth and outermost of the planets.

So far as we know, Pythagoras was the first person to teach that the earth was a globe that revolved around the sun. He was a Greek mathematician, astronomer, and geologist, who flourished about 600 B.C. He also taught many other things that are now commonplaces, but in his time they were very startling to many Greeks who still believed in what we call Greek mythology. The next person to suggest new explanations of the heavenly bodies was another Greek, Aristarchus, who about 250 B.C. advanced the theory that the earth is round, and that it revolves around the sun in one year. He even estimated the relative size of the sun, earth, and moon. Although his estimates are inaccurate, he did calculate that the sun is much larger than the earth.

About 500 years afterwards, Ptolemy, studied and edited the works of Aristarchus, and those of Hipparchus, another Greek astronomer; but after doing so he rejected the theory that the sun is the center of the solar system, and said that the earth is. His theory was believed by nearly everybody for almost 1300 years.

More than 2000 years after Pythagoras had advanced his theory that the earth revolves around the sun, Copernicus, a Polish astronomer, again put forward the same theory. He was laughed to scorn because nearly everyone and particularly the great men of the time believed that the earth was the center of the solar system.

It remained for an experimental scientist, Galileo, to prove the theory of Copernicus correct. Galileo made a telescope and with it he began to study the planets, Venus, Mercury, Jupiter, Saturn, and also the Milky Way. From his study he learned that the moons of Jupiter revolved around that planet. Moreover he furnished proofs that the planets revolved around the sun.

Galileo did not confine his observations to the heavens. Any simple experience in daily life that attracted his attention led to careful observation. It is said that while sitting in church he noticed the swing of a chandelier. Not having a watch, he computed the time of a complete swing in terms of beats of his pulse. He was amazed to discover that the time did not change as the length of the swing became shorter and shorter. From these observations and experiments he discovered the laws of the pendulum.

Another simple experience which led to another great discovery was that of Sir Isaac Newton and the apple. One day while in his garden he saw an apple fall. This experience led him to ask whether the force which pulls all objects toward the center of the earth extends beyond the earth to the moon and stars. If you continue your study of science, you will learn that this question led him to the discovery of the laws of gravitation.

Sometimes a great discovery is made by accident. A professor at the University of Copenhagen (Hans Christian Oersted) during a lecture held a wire carrying a current of electricity above a compass needle. He was amazed to see that the needle turned to one side. Three scientists—Joseph Henry in the United States, Ampère in France, and Faraday in England—directing their attention to this discovery, carried on experiments that led to the discovery of scientific laws that have made possible the dynamo, electric motor, telegraph, telephone, and radio.

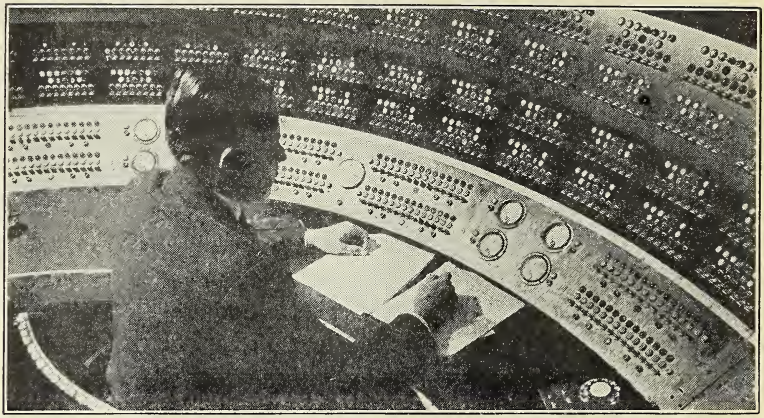


FIG. 3. The nerve center of a radio broadcasting station. A section of the main control desk of the National Broadcasting Company's new headquarters in Radio City, New York. The lights represent the different studios and the 85 stations on its coast-to-coast network.

A search for gold. Among the Egyptians, Phoenicians, Hebrews, and other ancient peoples the refining of metals from gold, silver, copper, iron, lead, and tin ores was a highly perfected art. But for many persons this art degenerated into a mysterious search for a method to change common metals such as iron and lead into gold. These men were known as alchemists. Over their pots and retorts in crude laboratories they carried on their activities in deepest secrecy. For centuries the study of chemistry in a scientific way was both hindered and helped by the activities of alchemists.

In time scientists such as Joseph Priestley in England, who discovered oxygen, and Lavoisier in France, who furnished proof that matter can neither be created nor destroyed, studied chemistry for its own sake. The applications to arts and industries they left to others. To these great scientists the search for truth seemed far more important than the search for gold.

Science attacks disease. Before the end of the eighteenth century a person whose face was not marked by smallpox was almost the exception. Advertisements for the sale of slaves frequently carried the high recommendation that all of them had had smallpox; thus their new owners were assured that they would not lose their slaves from this dread disease.

Students of this disease observed that persons suffering from a mild form of a disease called cow-pox did not get smallpox. But it remained for a scientist (Edward Jenner) to make a painstaking study of the origin and effects of cow-pox. He traced its origin to a disease common to horses which causes a swelling of the heel, from which a clear fluid is discharged. Cows infected with this fluid, he found, got cow-pox and from such cows human beings got cow-pox, a disease similar to smallpox. He advanced the theory that the germ could be spread from a horse to a cow by anyone who took care of both animals.

In 1796 he inoculated a patient with cow-pox. Two months later he exposed his patient to smallpox, but the patient did not contract the disease. The inoculation of the cow-pox had made him immune to it. This was a bold experiment for both scientist and patient. Would you have been willing to have had this experiment tried on you? Vaccination for smallpox is very common today. In many states children must be vaccinated before they can attend school. Smallpox is one disease which science has learned to control.

Other stories could be told of how scientists have succeeded in controlling dangerous diseases. Pasteur, after working for five years, discovered a successful treatment for rabies. Sir Ronald Ross discovered that the parasite that causes malaria gets into the blood of a human being through the bite of a certain kind of mosquito and in no other way. Dr. Carlos J. Finley of Havana advanced the theory in 1881 that a mosquito was the cause of yellow fever. Dr. Walter Reed of the United States directed the work of a commission appointed to investigate the theory of Dr. Finley. This commission proved that Dr. Finley's mosquito theory is correct.

How a question may be answered by experimentation. Suppose two persons are asked which is heavier, a quart of milk or a quart of water. One may say that a quart of water is the heavier and advance reasons why he thinks so. The other may say that a quart of milk is the heavier and state his reasons. The reason or reasons advanced by either one may be called a theory. A theory may be sound, it may lead to a sound theory, or it may be false. We can determine which of the theories is sound by performing a simple experiment. The following experiment will prove beyond doubt which is heavier, a quart of milk or a quart of water.

An experiment. To prove which is heaver, a quart of milk or a quart of water. Procure two clean, dry quart milk bottles. With stickers, label one "water" and the other "milk". Weigh each bottle accurately on a trip balance and record its weight. Then fill the bottle labeled "water" with water and the one labeled "milk" with milk. Weigh each and record its weight.

1. Weight of bottle and water ______________
2. Weight of empty bottle labeled "water" ______________
3. Difference (weight of water) ______________
4. Weight of bottle and milk ______________
5. Weight of empty bottle labeled "milk" ______________
6. Difference (weight of milk) ______________
7. Which is heavier, a quart of water or a quart of milk?

If the weighings have been exact, the data recorded accurately, and the computations made correctly, this experiment shows that the weight of one quart of milk is greater than that of one quart of water.

In the course of years the solution of many baffling problems and the determination of new facts have been made possible by the methods of science.

Problem: Has Science Changed the Daily Life of Men?

The wonders of the modern world. Have you ever thought how different our world is today from the world of ancient man? When you enter a room after dark, you may press a button and flood the room with light. You turn on the radio and hear the voices of people thousands of miles away. You turn a key and an automobile starts on its way, perhaps at a speed of 50 or 60 miles an hour. Airplanes with passengers and freight fly through the sky at a speed of three miles or more a minute. Ocean liners are constantly lowering the time taken to cross the ocean. Railroad trains with stream-lined engines and coaches travel from one city to another at the rate of a mile every thirty-five or forty seconds. Sound motion pictures re-enact events from all parts of the world.

When you are sick you can be taken to a hospital where doctors and nurses restore you to health. Diseases such as smallpox, typhoid fever, cholera, yellow fever, and diphtheria, which formerly caused the death of thousands of people yearly, have been brought under almost complete control.

Through discoveries made by scientists roses bloom in our gardens throughout the entire summer; new fruits and vegetables have been developed and green vegetables are available throughout the entire year; breeds of dairy and beef cattle, sheep, hogs, and chickens have been improved, thus giving us a bountiful supply of dairy products, meat products, and materials used in making our clothing. Many other advantages that we enjoy are due either directly or indirectly to the discoveries of scientists.

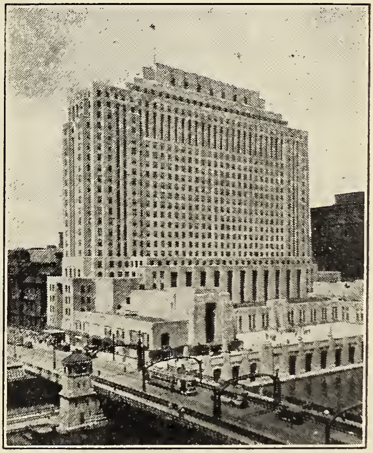


FIG. 4. Chicago Daily News Building. This fine building, constructed of Indiana limestone, shows one of the trends of modern architecture. Notice the street and the railroad tracks at water level. Here boats can be loaded without tying up traffic.

What has caused this great change from the world of ancient man to the wonderful world of today? The answer is: the minds of men who are scientists. The men that you have read about in this chapter, and many other gifted ones have added much to the world's great storehouse of knowledge. One great scientist, Huxley, has said that science is organized knowledge. Another has said that science is a method of obtaining new knowledge.

From the latter point of view science is most important as a means of education because its proper study tends to make you a young scientist, a self-reliant person, able to use what you know in dealing scientifically with a problem.

UNIT I

WHAT IS THE ATMOSPHERE AND HOW DOES IT AFFECT OUR DAILY LIVES?

Exploring the Atmosphere

An airplane flying through the air is a very common sight today. At times, we see single airplanes and then again we may see a squadron flying through the air in close formation. Such sights pass by almost unnoticed. As a modern transport plane with its load weighs about twelve tons, do you wonder what keeps it up?

No doubt when you have watched a bird flying, you have wondered what keeps the bird up. Undoubtedly, when you have been flying a kite, you have wondered what invisible substance makes flying possible.

From childhood, you have been told that air is necessary for life. Perhaps, you have tried to hold your breath longer than some of your playmates. If you have, you found that you were forced to resume breathing in a very short time. Your mother may have asked you to open the draft to the stove or furnace so that the fire would burn. You probably noticed, too, that air caused the fire to burn faster and brighter.

The approach of a storm fills us with wonder. Dust is swept up in clouds; trees sway in the wind, and loose paper is carried over house tops. When the wind finally sweeps against the house, it trembles as if it, too, were going to be blown away. What is this invisible substance in which birds, kites, balloons, airships, and airplanes fly and is so necessary for burning and for the breathing of all animals?

CHAPTER II

DO WE LIVE AT THE BOTTOM OF A GREAT OCEAN?

Do you know:

That water contains air? That an empty milk bottle is not really empty? What makes water gurgle when poured out of a small-mouthed bottle? How far above the earth the atmosphere extends? How many miles above the earth man has been?

That air has weight? That every square foot of your body is carrying a weight of 2000 pounds or more? What a barometer measures? What makes a barometer "rise" and "fall"? What lifts an airplane from the ground? Why an airplane cannot fly at a speed of thirty miles an hour?

PROBLEM: WHERE CAN AIR BE FOUND?

Every one has heard and used the words air and atmosphere. You know that we breathe air. You are familiar with the movements of air known as winds and storms, and perhaps you have even traveled by air. But even so, is what you know a real knowledge of the atmosphere? Test yourself by the questions at the beginning of this chapter.

Where can air be found? There are many ways by which it is proved that air completely surrounds the earth. The following experiments will show you that air is also present in many materials, and in containers that are commonly said to be "empty."

Experiment 1. To show that air is present in porous material. Fill a jar or pail two-thirds full of water. Plunge a dry sponge or a large piece of dry cloth quickly into the water. What rises from the cloth or sponge? Where did they come from? What are they?

If wood, soil, porous rock, or any other porous material is used, the result will be the same. The more porous the material, the greater the number of bubbles of air.

Experiment 2. To show that air is present in water. Slowly heat a pan of cold water. What forms on the bottom and sides of the pan? Where do they come from? What are they? What conclusion can you draw from these two experiments?

Throughout this book you will find many questions. Consider each of them carefully. They will help you to recall what you have learned and to master what you are studying.

Since air completely surrounds the earth, do you think that any open box, pail, tank, or other container can be really empty? What must be in it? As milk is poured from a bottle, air rushes in to take its place. What have you noticed, in pouring a liquid out of a small-mouthed bottle, that leads you to believe that air rushes into the bottle?

How many miles does the atmosphere extend above the earth? Scientists who have attempted to measure the height of the atmosphere do not agree. Some think that the atmosphere reaches fifty miles above the earth; others, that it extends one hundred or two hundred miles. Scientists have concluded that the burning of meteors as they rush through space far above the earth is due to the resistance of air. They think the atmosphere extends upward an even greater distance.

Lieutenant Soucek of the United States Navy flew a plane in June, 1930, to a height of 43,166 feet, a little more than eight miles. In August, 1932, Professor Piccard of the University of Brussels went still higher. With a companion in a free balloon he reached an altitude of 53,166 feet, a little more than ten miles. The intense cold and the rareness of the air at such heights make exploration extremely difficult and require careful preparations to safeguard the lives of the pilots.

On September 28, 1933 a French aviator, Gustave Lemoine, flew an airplane to a height of 44,822 feet. On September 30 of the same year, three Russians in a stratosphere balloon made a flight to a reported height of almost twelve miles (62,335 feet). In our own country, on November 20, 1933, Lieutenant Commander Settle, of the United States Army, piloted a stratosphere balloon to a height of 61,237 feet. In November, 1935, Captains Albert W. Stevens and Orvil A. Anderson reached an altitude of 72,395 feet or 13.71 miles. Their balloon flight into the stratosphere was sponsored by the National Geographic Society and the Army Air Corps. Even at these heights the balloons and airplanes were still supported by air, proving that they had not yet reached the upper limits of the atmosphere.

Although estimates of scientists do not agree as to the total height (or depth) of the atmosphere, all scientists agree that we live at the bottom of an immense ocean of air.

Spherical layers of the atmosphere. Scientists have subdivided the atmosphere into two great spherical layers, the *troposphere* and the *stratosphere.* The troposphere lies next to the earth and completely surrounds it. The height (depth) of the troposphere varies from an estimated height of about twelve miles at the equator to about four miles at the poles. This is the spherical layer in which we live and which we know as air. Its temperature varies from the different temperatures at the earth's surface to about 89 degrees below zero Fahrenheit (67 degrees below zero centigrade). How much colder is this than the coldest weather where you live? Scientists tell us that in this layer clouds are formed and storms arise.

Next to the troposphere and completely surrounding it is the stratosphere. In the stratosphere the temperature is always and everywhere the same; i.e. 67 degrees below zero centigrade. Here there is not enough air for a person to breathe and the sky is always clear.

As Dr. Piccard was the first person to ascend into the stratosphere, we owe our knowledge of the temperature and absence of clouds to his work. It is thought that this is the layer of the atmosphere that will be used for airplane travel between continents in the future. Did Lieutenant Soucek reach the stratosphere?

PROBLEM: DOES AIR HAVE WEIGHT AND EXERT PRESSURE?

You are living at the bottom of a vast ocean of air. Do you think air has any weight? Do you feel the weight of the air? Does air press against you? As you perform the following experiments, check your answers to these questions.

Experiment 3. To show that air has weight. Fit a 500-cc. Florence flask with a one-hole rubber stopper in which a glass tube with a stopcock has been inserted. Withdraw air from the flask by means of an exhaust pump, and close the stopcock while the pump is being operated. Why is the stopcock closed? Detach the pump and weigh the flask (Fig. 5). Open the stopcock. What happens? Weigh the flask again. Is there any difference in the two weights? What does this show?

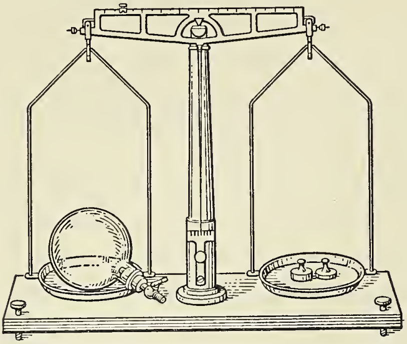


Fig. 5. Apparatus that may be used to show that air has weight.

Experiment 4. To prove that the atmosphere exerts pressure. Blow up a paper bag. Suck air out of the bag. What happens to the sides of the bag? What do you think caused this action?

Experiment 5. To show that the pressure of the atmosphere can crush a varnish can. Fit a one-hole rubber stopper, in which a glass tube has been inserted, into the opening of a varnish can. Attach an exhaust pump to the glass tube. Slowly operate the exhaust pump and at the same time watch the varnish can. What is happening to the can? What is being withdrawn from the varnish can when the exhaust pump is operated? What do you think crushed the varnish can?

If an exhaust pump is not available, place a small amount of water in the varnish can and boil the water until you are sure that the steam has driven most of the air out of the can (Fig. 6). Cork the can tightly and cool by pouring cold water upon it. What happens?

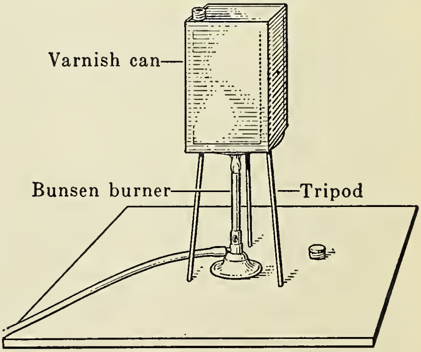


Fig. 6. Apparatus to show that the pressure of the atmosphere will crush a varnish can.

Experiment 6. To show that the atmosphere exerts pressure on water in a glass held upside down (inverted). Fill a drinking glass to the top with water. Cover the top of the glass with a piece of glazed paper. Now carefully turn the glass upside down (Fig. 7). (It is wise to perform this experiment over a sink.) Does the water come out of the glass? Hold the glass in the other positions indicated by the dotted lines and arrows. What happens? Notice that the paper is hollowed in as if something were pressing on it. Can you suggest what?

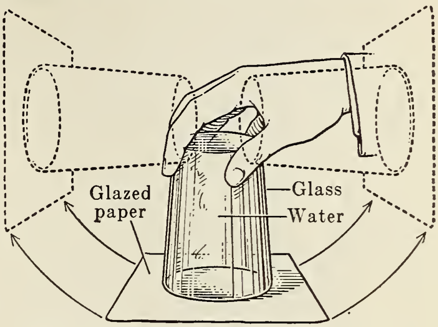


Fig. 7. What holds the water in the glass?

The water is actually held in the glass by the pressure of the atmosphere upon the paper. Scientists have calculated this pressure and found it to be 14.7 pounds per square inch at sea level. This is called normal atmospheric pressure or the normal pressure of air.

If the area of the top of the glass is four square inches, what is the pressure of the atmosphere in pounds on the paper?

How is the pressure of the atmosphere measured? The pressure of the atmosphere can be measured by an instrument called a *barometer*. The principle of the barometer was discovered by an Italian scientist, Torricelli, about the middle of the seventeenth century. He discovered this principle by an experiment much like the following.

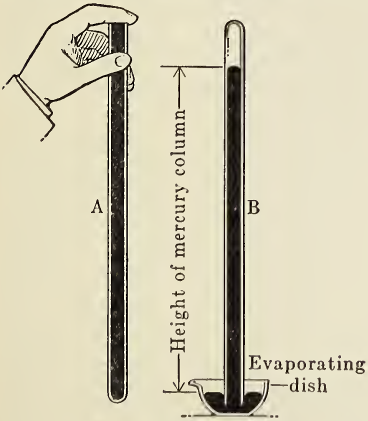


Fig. 8. What prevents all the mercury in tube *B* from coming down into the evaporating dish?

Experiment 7. To construct a mercury barometer. Fill a barometer tube such as tube *A* in Figure 8 with mercury. Place your finger tightly over the open end; then invert the filled tube in an evaporating dish half full of mercury. Keep your finger over the open end of the tube until it is below the surface of the mercury in the dish. Then remove your finger and hold the tube straight up and down, that is, vertically. What happens? With a yardstick measure the height of the mercury column. Compare its height with the reading of the laboratory barometer.

When the mercury ceased to fall in the tube, it came to rest because the pressure due to its weight was equal to the pressure of the atmosphere. At sea level the pressure of the atmosphere will support a column of mercury in a barometer tube about thirty inches high (Fig. 9). Measured in centimeters, this is about seventy-six centimeters high (760 millimeters). Consequently, in reading a barometer we say that the air pressure is 30 inches, or 76 centimeters, meaning, of course, that the pressure of the atmosphere is great enough to support a column of mercury 30 inches, or 76 centimeters, high. Could a barometer be made of any other liquid than mercury? What advantage has mercury over most other liquids?

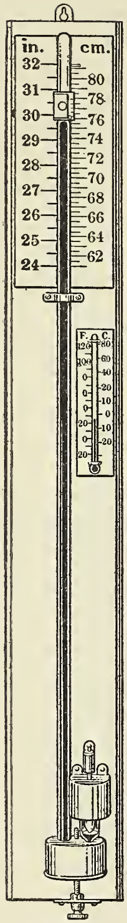


FIG. 9. What is the air pressure in centimeters shown by this barometer?

What causes a barometer to "rise" and "fall"? Torricelli concluded that the space in the tube above the mercury column was empty; that is, it did not contain anything to press down on the mercury. Such a space, which does not contain solids, liquids, or gases, is called a *vacuum* (p. 24). Because the space above the mercury column is a vacuum, the mercury "rises" or "falls" freely in the tube with any increase or decrease of atmospheric pressure on the mercury in the dish. If the pressure increases, the mercury is forced up (rises) in the tube. If the pressure decreases, the mercury "falls" in the tube. A change in the height of the mercury column is known as a "falling" or "rising" barometer.

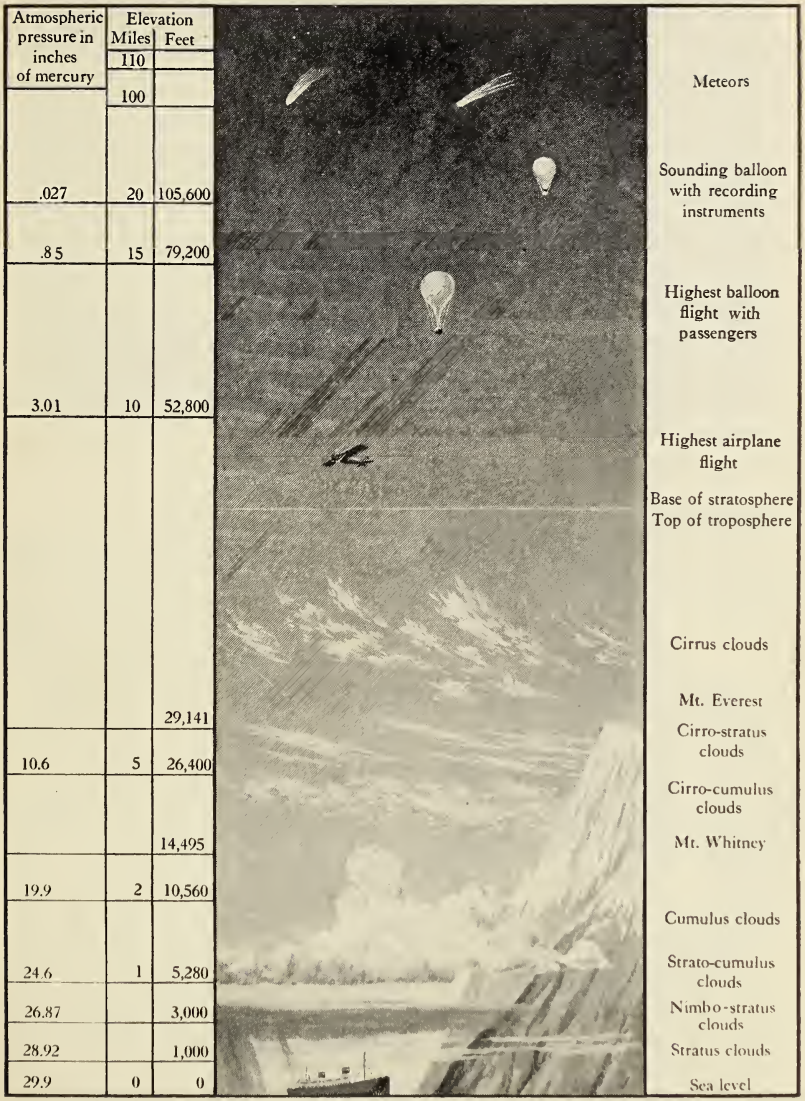
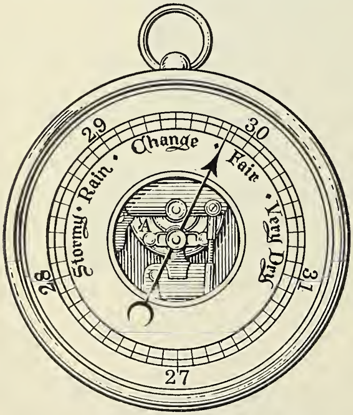


FIG. 10. Try to explain from this drawing why scientists believe that the height of the atmosphere is more than 100 miles above sea level.

Does a change in altitude cause a change in atmospheric pressure? Pascal, a famous French scientist, thought that the pressure of the atmosphere must decrease, the higher one goes above sea level. In order to test the truth of his theory, he carried a barometer to the top of a high tower and was delighted to observe that the column of mercury had fallen. Pascal wrote to his brother-in-law, who lived near a high mountain, and asked him to verify his theory by a second experiment. His brother-in-law carried a barometer up a mountain to a height of 3300 feet; he was astonished to observe that the mercury had sunk in the tube a little more than three and one half inches. From these two experiments Pascal concluded that his theory was correct, namely, that the pressure of the atmosphere decreases as one ascends above sea level. Figure 10 shows that the pressure of the atmosphere decreases as the distance above the earth increases. Did Pascal use the scientific method to test his theory? Explain.

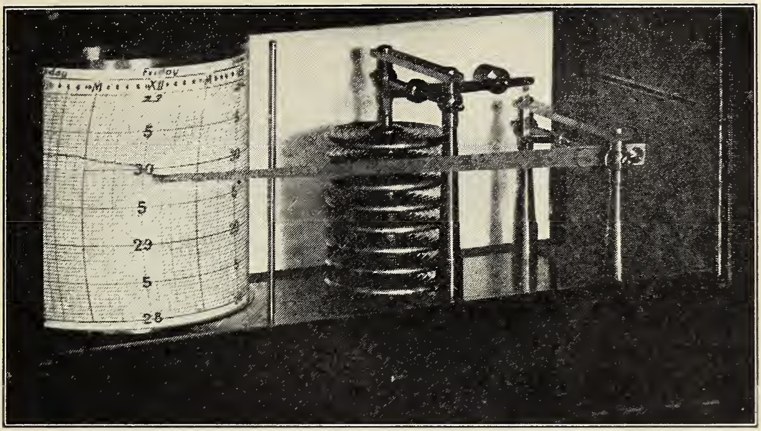
What is an aneroid barometer? The mercury barometer (Experiment 7) with its long tube is inconvenient to carry and impractical for many purposes. In consequence another kind called the *aneroid barometer* (Fig. 11) has been invented. This barometer measures accurately very small differences in air pressure.

The aneroid barometer consists of a shallow metallic box from which some of the air has been removed. One side of this box is metal, so thin and flexible that it moves inward or outward with any change in the pressure of the atmosphere. When the pressure of the atmosphere increases, this thin metal side is forced in slightly. What would happen when the pressure of the atmosphere decreases? The back and forth movement of this thin metal side causes a hand to move on a dial. The dial is marked in inches,



Courtesy U. S. Weather Bureau

FIG. 11. What air pressure is registered on this aneroid barometer?



Courtesy U. S. Weather Bureau

FIG. 12. What was the atmospheric pressure at the time this picture was taken?

centimeters, pounds per square inch, altitude, etc., according to the use for which a particular barometer is intended.

The principle of the aneroid barometer is also used in the *altimeter*, an instrument by means of which aviators can determine their height above sea level.

What is a barograph? To make a continuous record of changes in the pressure of the atmosphere needed by weather forecasters, aviators, etc., an instrument called a *barograph* (Fig. 12) is used. It consists of a series of metal boxes such as the one used in an aneroid barometer, placed one above the other and so connected that any change in the pressure of the atmosphere can be recorded on a drum turned by clockwork. This drum may make one rotation in twenty-four hours or in seven days. A cylinder of graph paper is fitted around the drum, and on this paper an unbroken line is drawn by a pen point moved by machinery attached to the series of metal boxes. This line is a continuous record of the changes in atmospheric pressure.

PROBLEM: HOW DOES MAN USE THE AIR FOR TRAVEL?

For centuries men have tried to imitate the flight of birds. Although balloons had been used for several hundred years, it

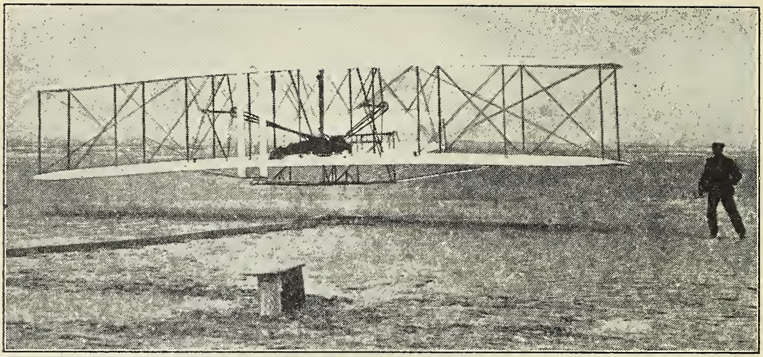
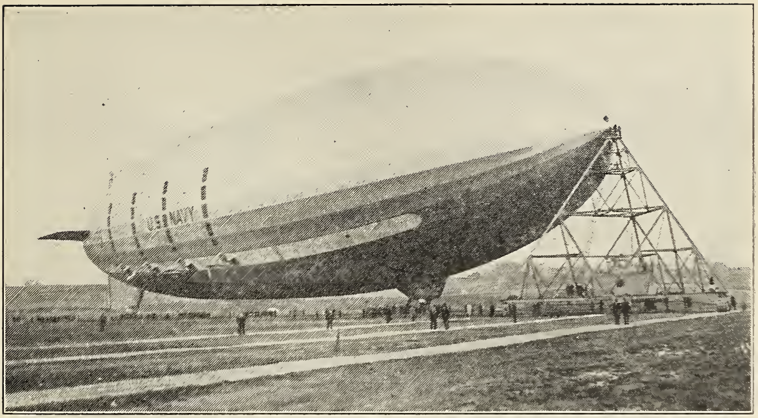


FIG. 13. The first successful airplane flight. For three years the Wright Brothers experimented with gliders at Kitty Hawk, North Carolina. Finally they equipped a glider with an engine and made the first airplane flight. Orville Wright was at the controls. His brother Wilbur ran alongside the plane and held the wing until the plane "took off."

was not until 1903 that the first practical flying machine was constructed. On December 17 of that year, an airplane with engine and pilot rose from the ground and flew a distance of 850 feet (Fig. 13). Not long afterwards the air began to be used as a medium of travel. Many improvements have been made over the first flying machine, until now the hum of airplane motors is as familiar to dwellers along air routes as the puffing of a locomotive is to persons who live near a railroad.

The airship. One kind of aircraft is the *airship,* a motor-driven, gas-filled balloon, lighter than air (Fig. 14). It is designed to offer as little resistance as possible to the air, that is, it is streamlined. An airship floats in the air because it contains gas "cells" filled with hydrogen or helium, either of which is lighter than air. In designing an airship the engineer calculates the lifting power of the gas cells, when filled with the gas to be used, to make sure that the airship and its load will rise from the ground.

The Macon, an airship which belonged to the United States Navy and crashed in 1935, had a total lifting power when inflated with helium of 410,000 pounds. This airship, with its eight engines of 560 horsepower each and the machinery for guiding it,



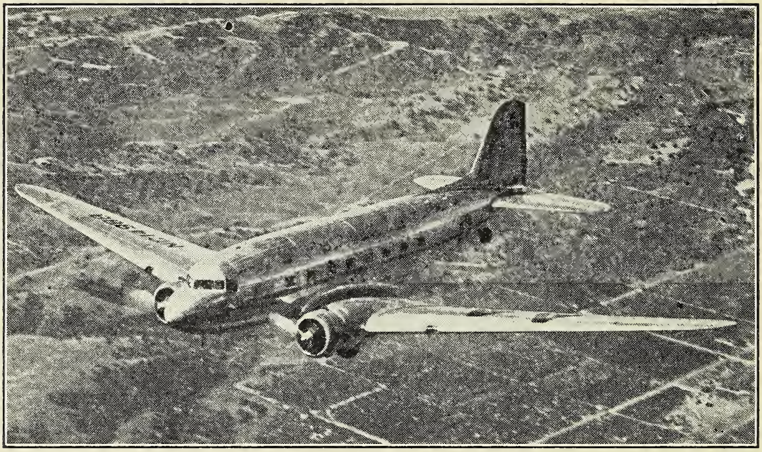
Courtesy Goodyear Rubber Co.

FIG. 14. The Macon attached to a mooring mast near Akron, Ohio, ready for its first flight. What happened to this airship?

weighed about 237,000 pounds. Therefore it had a lifting power of more than 173,000 pounds (86.5 tons) which could be used to carry crew, passengers, and cargo. Most airships have crashed or burned a few years after being constructed. The passenger airship Hindenburg, after making ten round trips between Germany and United States during the summer of 1936, took fire and burned at Lakehurst, New Jersey, May 6, 1937.

The airplane. Another kind of aircraft is the *airplane* (Fig. 15). As the motor turns the propeller, the propeller acts like a screw; it bores into the air and pulls the rest of the plane after it. As the airplane moves forward the front edge *E* (Fig. 16) of the wing parts the air. The air that passes upward is hurled away from the top surface of the wing, thereby the air pressure on top of the wing is reduced. Air that passes downward strikes the lower surface of the wing, thereby the air pressure on the bottom of the wing is increased. As a result, the pressure on the bottom surface of the wing is greater than the pressure on the top surface.

As the speed of an airplane increases, this difference in pressure increases. When the lifting force caused by the difference of pressure is greater than the weight of the airplane, the airplane will be lifted off the ground. The speed of an airplane must always



Courtesy American Airlines

Fig. 15. This monoplane carries 21 passengers, two pilots and a stewardess. Its cruising speed is 177 miles per hour.

be great enough to create a lifting force greater than the weight of the plane, if the plane is to remain in the air. This speed for most planes is about sixty miles per hour.

Today planes fly from the East Coast to the West Coast across the United States between daylight and dawn. Planes fly between New York and Washington in less than eighty minutes. The carrying of mail, freight, and passengers by airplane is an established means of transportation in most countries. Every important trade center has its airport; planes arrive and depart according to schedule. Even small towns have airports.

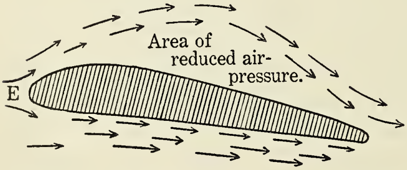


Fig. 16. From this drawing try to tell how a lifting force is produced by the action of air on an airplane wing.

Flying boats that weigh 20 to 25 tons span the Pacific and carry forty passengers and 5000 pounds of cargo. When you see an airplane flying through the air as gracefully as a huge bird, you realize that air is indeed a very real substance.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

airplane
airship
altimeter
altitude
aneroid
atmosphere
barograph
barometer
exhaust pump
helium
mercury
Pascal
pressure
stratosphere
Torricelli
troposphere
vacuum
vertical

Write the number of each item on your paper and after it the word that completes the statement.

1. As the distance above sea level increases, air pressure __________.

2. The total force exerted by the air on a surface of ten square inches at sea level is __________ pounds.

3. A self-recording barometer is known as a __________.

4. In a perfect vacuum the reading of a barometer would be __________.

5. A barometer "rises" when air pressure __________.

6. The mercury barometer was invented by __________.

7. The barometer used on airplanes is known as an __________.

Which item in each of the following lists does not belong with the others?

8. Altimeter; mercury barometer; thermometer; barograph; aneroid barometer.

9. Lieutenant Commander Settle; Admiral Byrd; atmosphere; troposphere; stratosphere.

10. Airship; airplane; helium; balloon; Macon.

Which of these statements are true? If any are false, re-state them in correct form.

11. An airplane is raised from the ground by the pressure of the atmosphere.

12. A "falling" barometer indicates an increase in atmospheric pressure.

13. An airplane is an aircraft that is lighter than air.

14. An airplane can fly as slowly as fifteen miles an hour.

CHAPTER III

HOW ARE ATMOSPHERIC PRESSURE AND COMPRESSED AIR USED TO DO WORK?

Do you know:

That when you draw soda water through a straw, the soda water is being pushed into your mouth by air? That air pushes ink into your fountain pen when you fill it? That air pushes dirt into a vacuum cleaner? That filling a fountain pen, sweeping with a vacuum cleaner, and pumping water with a lift pump all depend upon the same thing? Why a lift pump cannot be used to raise water more than thirty-four feet? That water can be made to run uphill?

What compressed air is? How compressed air helps to protect the passengers on a train from accidents? The cause of a "blow-out" in an automobile tire? That football and basketball games depend on compressed air? What makes a tennis ball "dead"?

Problem: How Is the Pressure of the Atmosphere Used to Do Work?

Air pressure in a partial vacuum. If part of the air in a closed container is removed, the part that remains expands and occupies all the space in the container. In doing so it becomes thinner or more rare and consequently the pressure of the air inside the container is less than the pressure of air outside. If the space inside a container is filled with air thinner than air outside of the container, it is called a *partial vacuum.* A perfect vacuum is a space from which all matter has been removed. In everyday usage, however, a space from which most of the air has been removed is called a vacuum.

What is the normal pressure of air? Would a space filled with air exerting a pressure of 8 pounds per square inch be a partial vacuum? Explain. When you made a mercury barometer in Experiment 7, was the space above the mercury a perfect vacuum? What was the air pressure in this space?

Does the pressure of air make it possible to drink soda water through a straw? If you were told that soda water could not be drawn up through a straw unless the surface of the liquid was open to the air, would you believe it?

Let us perform an experiment to find out whether this statement is true or false.

Experiment 8. To prove that air pressure is necessary to draw soda water through a straw. Fit a flask with a one-hole stopper in which a glass tube has been inserted (Fig. 17A). Remove the stopper and fill the flask with water; then insert the stopper in such a way that all the air will be forced out. Does the water rise in the tube a little? Is the surface of the water in the flask open to the air? Put the end of the tube in your mouth and attempt to drink the water. What is the result? How do you account for it?

Take out the rubber stopper, remove the glass tube, and insert one end of the tube in the water (Fig. 17B). Is the surface of the water in the flask now open to the air? Put the end of the tube in your mouth and attempt to drink the water. What happens? Explain.

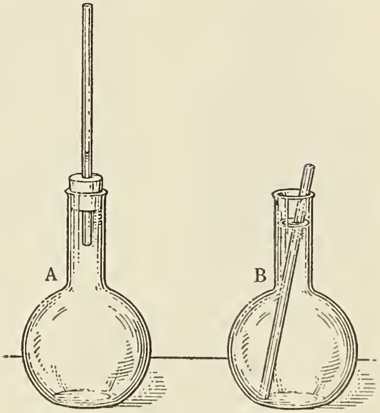


FIG. 17. From which of these flasks could you drink water through the glass tube? Why?

As you withdrew air from the tube, a partial vacuum was formed in it, and consequently the pressure of the air on the surface of the water in the flask became greater than the pressure in the partial vacuum in the tube. As a result the air pressure on the water forced water up the tube. If enough air is drawn out of the tube the liquid will be forced into your mouth. Would you expect this same effect if some other liquid had been used?

Does the pressure of air make it possible to pump water? The following experiment will help to answer this question.

Experiment 9. To show the principle of the lift pump. Into the end of a short glass tube, about three-quarters of an inch in diameter, fit a plunger (Fig. 18); a cork attached to a handle and wrapped with cloth so that it fits snugly into the tube will do. Push the plunger through the tube nearly to the other end. Place this end of the tube in water and draw the plunger upward. Does water rise in the tube? Why?

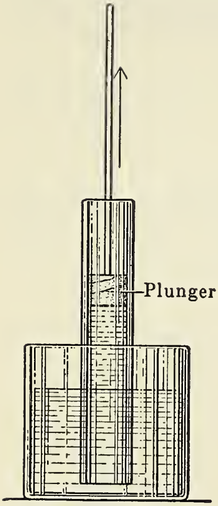


FIG. 18. What happens when the plunger is raised?

When the plunger was drawn upward a partial vacuum was created in the tube. The pressure of the air on the water forced the water up into the partial vacuum in the tube. In this experiment drawing the plunger upward formed a partial vacuum in the tube in the same way that one was formed by withdrawing air from the tube in Experiment 8.

How high can water be raised by air pressure? In 1640 the Duke of Tuscany had a deep well dug near Florence. When the pump was installed, he was greatly surprised to find that water could not be pumped to the surface. He asked Galileo to find the reason and to overcome the difficulty. Galileo planned an experiment to determine the height to which water can be raised by the pressure of the atmosphere, but he died before the experiment was performed.

His pupil, Torricelli, carried out the experiment, using mercury instead of water. As you have learned, he knew that air pressure would support a column of mercury about 30 inches high. He knew also that mercury is about 13.6 times as heavy as water. From this he calculated that air ought to support a column of water 13.6 times 30 inches, about 34 feet high. Therefore water cannot be raised with a simple lift pump more than 34 feet.

As the surface of the water in the well owned by the Duke was more than 34 feet below the surface of the ground, explain why the water could not be pumped to the surface.

Experiment 10. To observe the operation of a simple lift pump. First notice the location of valves A and B in a laboratory lift pump. Then place the pump in a vessel of water and operate it. During the first upward movement of plunger D is valve B open or closed? Suggest a reason. During the first downward movement of the plunger is valve B open or closed? Is valve A open or closed? Suggest a reason. When is valve A open? closed? When is valve B open? closed? Suggest reasons.

During the first upward movement of plunger D, a partial vacuum is created in Chamber C. As the air pressure in C is now less than the air pressure on the water, water is forced into chamber C, opening valve B as it enters as shown in (1).

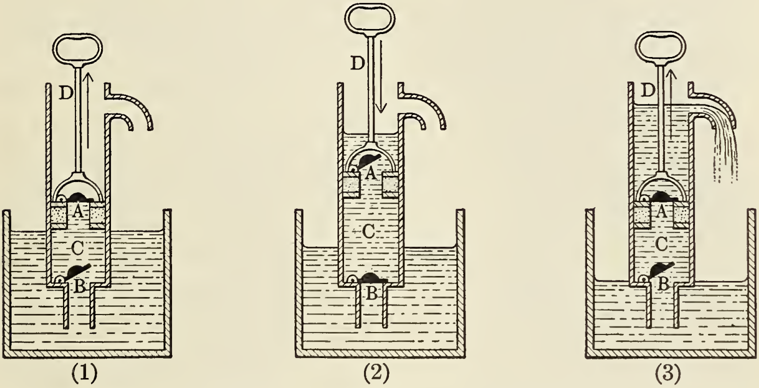


Fig. 19. These drawings help to show how a lift pump raises water. Explain why water does not flow out of a lift pump on the first upward movement of the plunger.

During the first downward movement of the plunger, valve B is closed by the downward pressure of water upon it; at the same time valve A in the plunger is forced open by the upward pressure of water against it. As a result water enters the part of the chamber above the plunger as shown in (2). As the plunger is raised again, valve A is closed by the downward pressure of the water, and the water above the plunger is lifted to the level of the spout, through which it escapes (3). At the same time a partial vacuum is created; the lower valve is again forced open and more water enters the chamber as before.

This kind of pump is used today in rural sections to pump water from wells, cisterns, and springs.

The force pump. In the force pump (Fig. 20) the plunger *A* does not have a valve. When the plunger is raised, a partial vacuum is created in chamber *B*; thereby the pressure of the air on the surface of the water in the well forces water through valve *E* into the chamber *B*. During the downward movement of the plunger, valve *E* closes. Why? Water is forced through valve *D* into discharge pipe *F*. As you can see, the flow of water through *F* would vary as the plunger moves up and down. To make the flow of water uniform an air chamber *C* is connected to the pipe. The flow of water through the pipe into chamber *C* compresses the air in chamber *C* into a smaller space. Would this compressed air exert a greater pressure than 14.7 pounds per square inch? Valve *D* does not allow the water to flow back into chamber *B* when the plunger rises. The compressed air in chamber *C* exerts a force that causes water to flow from pipe *F* in a uniform stream as long as the pump is operated.

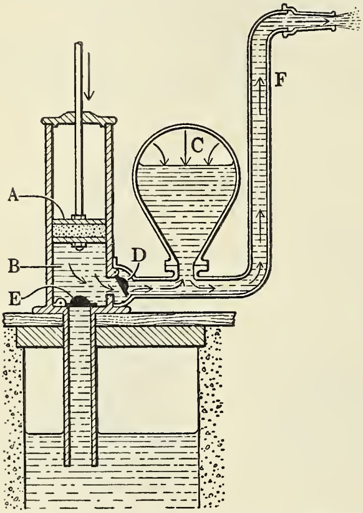


FIG. 20. One kind of force pump, showing that as the plunger goes downward, water is forced into air chamber *C*. What is the purpose of an air chamber similar to *C* seen on a fire engine?

As the pressure of the compressed air is limited, the nozzle on the discharge pipe must be smaller than the pipe which supplies water to the air chamber in order to keep the flow of water uniform.

What is pressing down on the surface of the water in the well? What forces water up into and through the pump? Also, what is above the surface of the water in chamber *C* which forces water out of the discharge nozzle? Can the force pump be used to pump water higher than 34 feet? Explain.

Special problem. Another kind of force pump is shown in Figure 21. This pump is different from the force pump just studied in that it has valves in the plunger. In pumping water with this pump, the pressure of the atmosphere and the pressure exerted by compressed air serve the same purposes as in the other force pump. Explain how this pump operates.

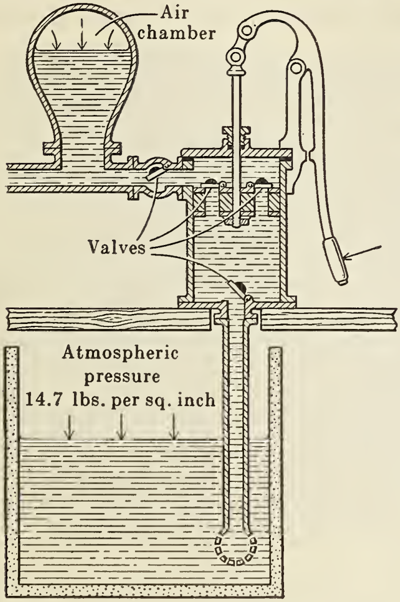


Fig. 21. What is the purpose of each of the valves shown in this kind of force pump?

Experiment 11. To construct a siphon. Heat a piece of glass tubing twelve or fourteen inches long in a Bunsen flame and bend it into a U-shape with one arm longer than the other (Fig. 22). After the tube has cooled, fill it with water and then, holding a finger over each open end, insert the end of the shorter arm in a jar of water. Take your fingers from the ends of the tube. What happens?

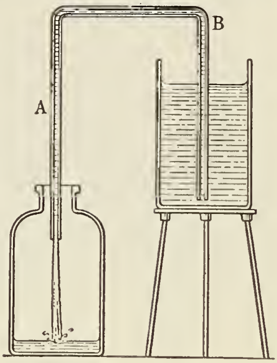


Fig. 22. Why does the water flow in the siphon from *B* to *A*?

The siphon. A siphon is always interesting because in it water runs uphill. To make a siphon work it must be filled with water, and the level of the water in which the shorter arm is immersed must be higher than the outlet at the end of the longer arm.

Water starts to flow in the siphon because the weight of the water in the longer arm is greater than the weight of the water in the shorter arm. The pressure of the air on the surface of the water in which the shorter arm is immersed keeps the tube full of water (unless the highest part of the tube is more than 34 feet above the surface of the water).

Siphons may be used to bring water from a pond or spring over slight elevations not more than 34 feet higher than the source to any place that is at a lower level than the source. Siphons are used in industry to transfer liquids from one container to another at a lower level. A siphon can also be used to draw off the upper part of a liquid without disturbing the lower part of it. How could a siphon be used to draw cream from the top of a milk bottle? How could a motorist use a siphon to remove gasoline from the gas tank on his car?

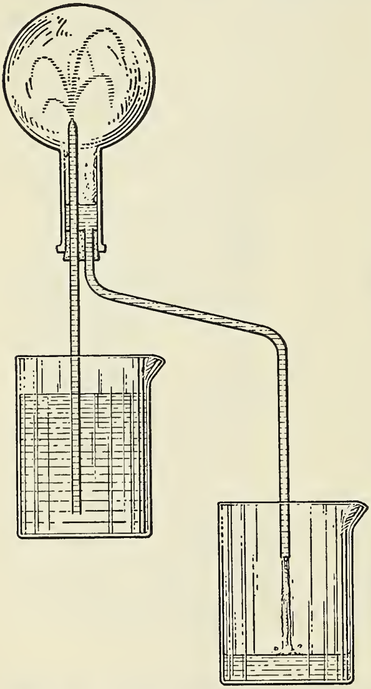


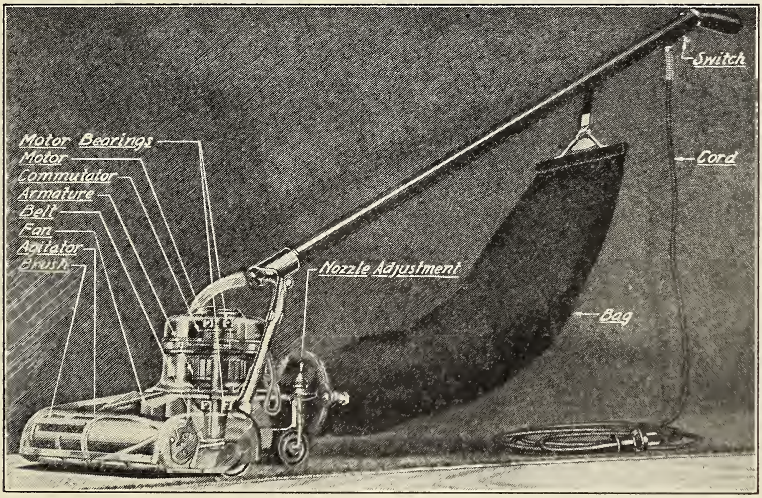
Fig. 23. What causes the partial vacuum in the inverted flask?

Special problem. To construct a fountain in a vacuum. Set up the apparatus shown in Figure 23. The shorter tube should end in a jet inside the flask, while the longer tube should just reach through the stopper. A little water must be placed in the flask to start the siphon. Why? What causes the water to spray upwards inside the inverted flask?

How does a vacuum cleaner operate? One of our common household appliances, the vacuum cleaner, makes use of a partial vacuum in its operation. The following experiment will show the principle on which a vacuum cleaner operates.

Experiment 12. To illustrate the principle of a vacuum cleaner. Tear a piece of paper into small bits and place them on a table. Roll a sheet of paper into the form of a cylinder having a diameter of about one-half inch. Put one end of the cylinder to your mouth and the other end near the bits of paper; draw in your breath rapidly. What happens? Explain. Was a partial vacuum produced in the cylinder? How?

When a vacuum cleaner is used, a partial vacuum is produced in the vacuum chamber by a fan operated by an electric motor (Fig. 24). The air on the outside rushes into the vacuum chamber with sufficient force to carry bits of dirt and paper with it. Why?



Courtesy the Hoover Company

FIG. 24. Which of the parts of this vacuum cleaner make it possible for air pressure to help clean your rugs?

The principle of the vacuum cleaner is used in machinery for unloading dried coconut and other light materials from holds of ships; also cotton from the farm wagons in which it is delivered to the cotton ginning plants. In factories dust from woodworking machines and grinding wheels is removed by this method.

Is air pressure necessary to fill medicine droppers and fountain pens? When the small rubber bulb of a medicine dropper is pinched, some of the air inside is forced out. When the pressure on the bulb is released, a partial vacuum is formed in the tube and bulb and air rushes in as the bulb returns to its original shape. If the open end of the tube is immersed in a liquid, the bulb squeezed and then released, the pressure of the air on the surface of the liquid is greater than the pressure of air in the bulb; therefore some of the liquid is forced into the tube of the medicine dropper. If the rubber bulb is again pinched, the air in the bulb is compressed, thus forcing the liquid out.

A fountain pen is filled in much the same way as a medicine dropper. Explain what happens when a fountain pen is filled. As you have seen, the operation of a medicine dropper and a fountain pen depends upon air pressure.

PROBLEM: HOW IS COMPRESSED AIR USED TO DO WORK?

Uses of compressed air. If air is forced into a closed container until the pressure of the air in the container is greater than 14.7 pounds per square inch, the air in the container is called compressed air. This air is used for many different purposes. The tubes used to send messages and money from one part of a building to another are operated by compressed air. The lives of men working beneath the surface of water depend in part upon the force exerted by compressed air. This force prevents the pressure of water from crushing the diving bells, caissons, or diving suits in which such men work. Sometimes tools, such as drills and hammers, are operated by compressed air. Passengers riding in motor coaches, street cars, and trains owe their safety in part to the use of air brakes operated by compressed air. So you see that compressed air is used in many ways that are helpful in our everyday life. What other uses of compressed air can you mention?

The operation of an air brake. The safe operation of a train depends partly upon the use of compressed air. Attached to the locomotive is a tank into which air is pumped until the air in the tank is highly compressed. A jointed pipe *A* (Fig. 25) connects this tank with a small tank *B* on each car. Through this pipe compressed air may flow into any or all of the small tanks. The compressed air in each small tank operates the brakes on the car to which it is attached. Each car, therefore, has its own supply of compressed air for operating its brakes. A train going at high speed can be stopped quickly and safely by a system of air brakes.

The air brakes on a street car operate on the same principle

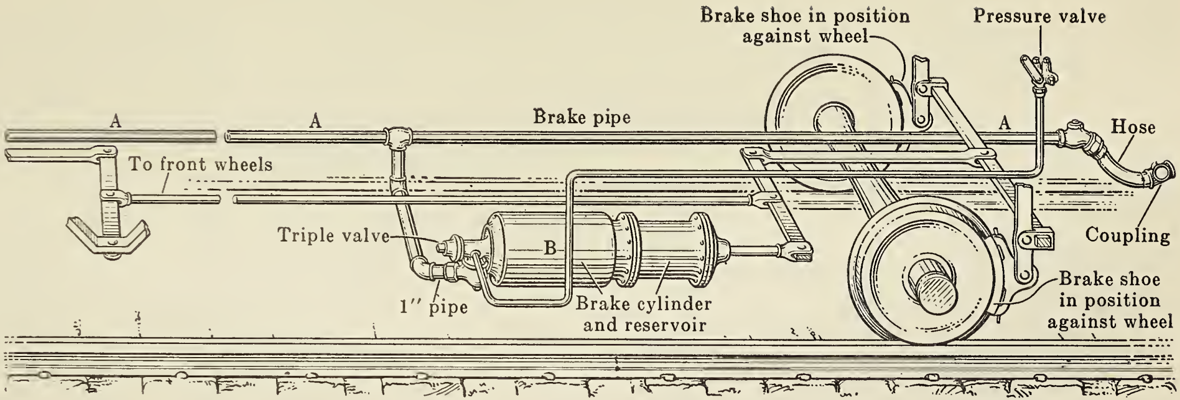

Brake shoe in position against wheel
Pressure valve
A
A
Brake pipe
A
Hose
To front wheels
Coupling
Triple valve
B
1″ pipe
Brake cylinder and reservoir
Brake shoe in position against wheel

Fig. 25. Diagram of brake equipment for a freight car. Inside the brake cylinder a piston moves back and forth much like one in the steam chest of an engine. In a reservoir under a freight car the air pressure is about 70 pounds per square inch. When the engineer wishes to apply the brakes, he operates a control in the cab which reduces the pressure of the air coming from the engine. The air pressure in the reservoir under the car then forces the piston in the brake cylinder toward the right with great force and tightens the brake shoes against the wheels. When the pressure of the air from the engine is increased again to equal the pressure in the reservoir, a spring moves the piston to the left, releasing the brake shoes from the wheels.

as the air brakes on a train. Air is compressed in a tank beneath the floor of the car by a pump driven by a small electric motor.

Pneumatic tools. You have just learned that certain tools may be operated by compressed air. Such tools are called pneumatic tools, that is, air-operated. In mining coal and quarrying stone pneumatic drills are employed. In the erection of steel buildings and bridges, pneumatic hammers clinch the rivet heads. Pneumatic tools have become a part of the modern equipment needed in many industries.

Inflating automobile tubes. Compressed air is used in automobile tubes. A foot pump may be used to pack air into the tube. A valve permits air to be pumped into the tube but prevents compressed air from escaping. As more and more air is forced into the tube, the air is more and more compressed, and in consequence the air pressure within the tube becomes greater and greater. This pressure of compressed air inflates the tube.

At service stations, a gasoline engine or an electric motor is used to pump air into a closed tank. As needed, compressed air from this tank is used to inflate tubes. The loud report of a "blowout" is due to the rapid expansion of compressed air.

Balls for athletic games. Balls used in certain athletic games contain compressed air. The success of the players depends so much upon the pressure of the compressed air within a ball, that the regulations governing each game specify what this pressure must be. In basketball, for example, the ball should be inflated until the air pressure within it is about 27 pounds per square inch but a pressure gauge will show a pressure of about 14. Why? What other games depend upon compressed air?

Caissons. Men working many feet beneath the surface of water are dependent upon compressed air, not only for air to breathe but also for keeping water out of the place in which they are working. In laying foundations for bridges, docks, piers, and the like, men frequently work in a large steel chamber called a *caisson* (Fig. 26), which is sunk beneath the surface of the water and forced down into the mud. Air is then forced into the caisson until the air pressure is great enough to keep water from entering it. The men who work in the caisson enter it by

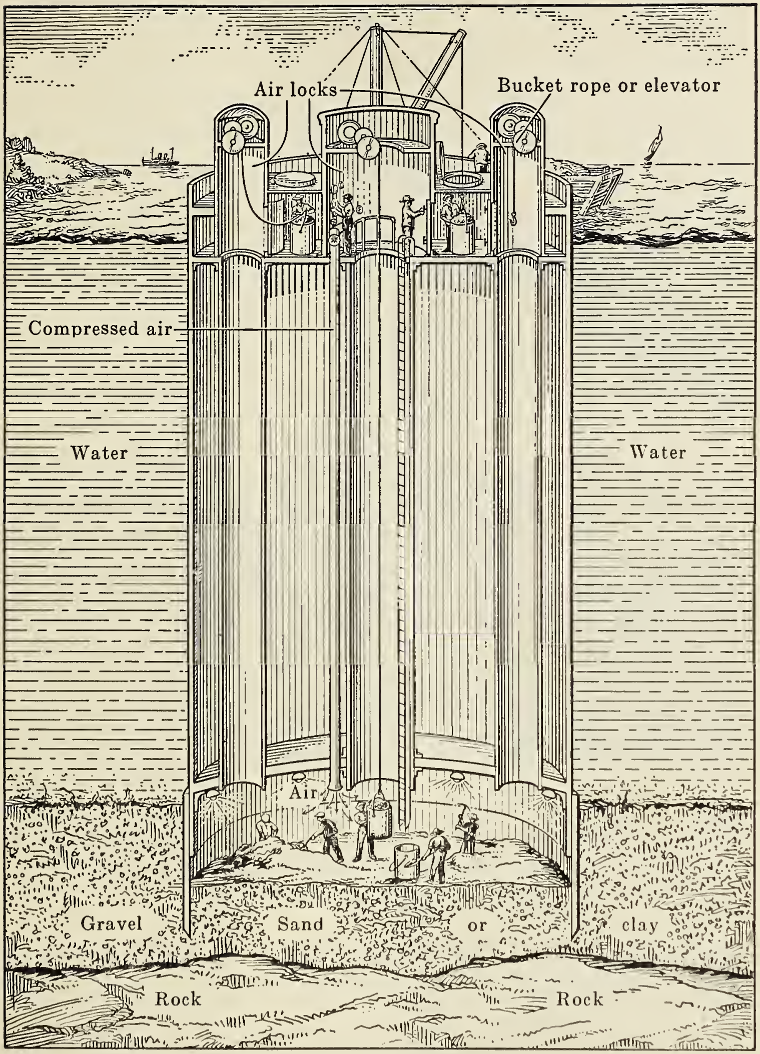
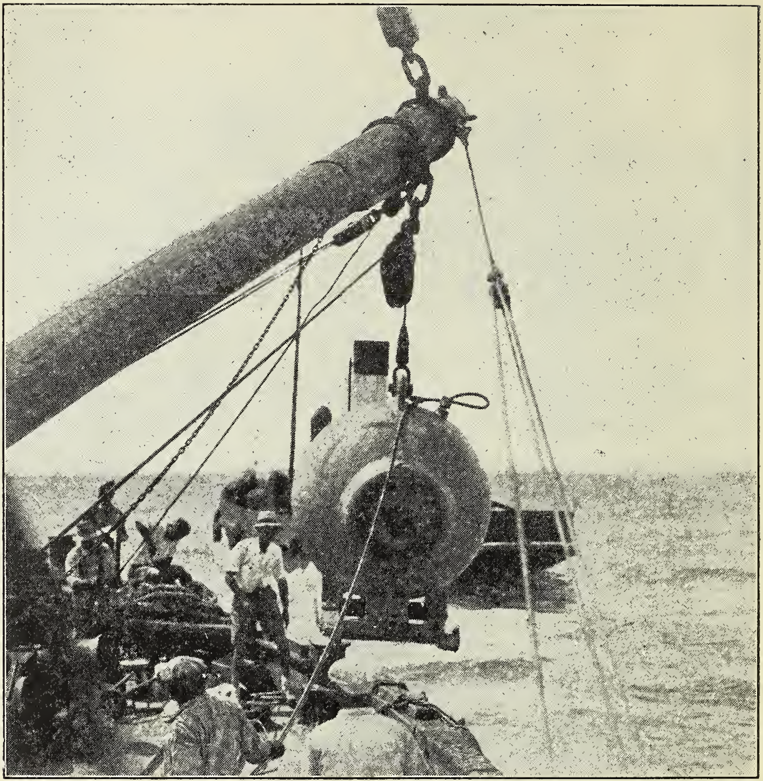


FIG. 26. A caisson. In what two ways does air pressure make it possible for work to be done on the bottoms of rivers and harbors? The use of the caisson illustrates how man has overcome certain forces of nature. What are they?



Courtesy William Beebe

Fig. 27. The bathysphere was devised for the use of scientists who wished to study plant and animal life in the deep sea. Why is the bathysphere made so strong? Notice the window through which an observer can watch and even photograph marine life.

means of "air locks." In these air locks the workmen become accustomed gradually to the pressure of the compressed air in which they are to work.

The diving suit. To enable men to work under water a diving suit is sometimes used, or sometimes a bathysphere (Fig. 27) is used.

For work in shallow water, a diving suit may consist of a hood which is placed over the diver's head. Air is pumped into the hood through a tube which extends to the surface of the water.

For work in deeper water, a diver wears a suit that protects his entire body from the pressure of the water. Formerly, with a diving suit a diver could descend to a depth of 150 feet and remain there for half an hour. But now a diver can descend to a depth of 500 feet and stay for three or four hours. The suit used today is three feet wide and eight feet high, and weighs about 1000 pounds.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

air brake
caisson
compressed air
partial vacuum
force pump
Galileo
lift pump
plunger
pneumatic
siphon
valve

Write the number of each item on your paper and after it the word that completes the statement.

1. During the up stroke of a lift pump the valve in the plunger is __________.
2. A liquid is forced up the shorter arm of a siphon by __________.
3. Footballs and basketballs are filled with __________ air.
4. Tools operated by compressed air are known as __________ tools.
5. Brakes on trains and coaches are operated by __________ air.
6. Air pressure at sea level can support a column of mercury __________ inches high.
7. At sea level air pressure will raise water about __________ feet.

Which item in the following lists does not belong with the others?

8. lift pump; partial vacuum; water; air pressure; compressed air.
9. siphon; lift pump; basketball; medicine dropper; fountain pen.
10. vacuum; pneumatic tools; automobile tires; caisson; diving suit.

Which of these statements are true? If any are false, re-state them correctly.

11. A lift pump will not pump water in a vacuum.
12. A vacuum cleaner is operated by compressed air.
13. A siphon will lift water over an elevation a mile high.
14. A partial vacuum contains some air.
15. Water cannot be forced more than thirty feet into the air with a force pump.

CHAPTER IV

WHAT IS THE ATMOSPHERE MADE OF?

Do you know:

That air is a mixture of gases? What part of air is oxygen? What part is nitrogen? That we breathe nitrogen even though the body does not use it? What gas is used to fill electric light bulbs? What gas is used in electric signs? That a gas can be poured on a fire to put it out?

How to test a gas to see whether it is oxygen? That gases are given off when a fuel burns? What substance is the most abundant in the earth's crust? That the same process is going on when a piece of wood burns, when an iron nail rusts, and when an apple rots? That it is impossible to burn coal in a vacuum?

PROBLEM: WHAT GASES MAKE UP THE ATMOSPHERE?

The atmosphere is composed of gases. The two gases which comprise the greater part of the atmosphere are *oxygen* and *nitrogen*. Study Figure 28. What per cent of the volume of air is nitrogen? What per cent oxygen? The remaining one per cent is made up of carbon dioxide, water vapor, and the rare gases helium, argon, neon, krypton, and xenon. The most abundant of the rare gases is argon.

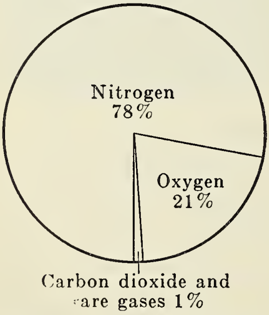


FIG. 28. Read from this graph the per cent by volume of the gases that make up air.

Carbon dioxide forms from three to four parts in ten thousand parts by volume of the atmosphere, that is, from .03 to .04 per cent. The volume of water vapor in the atmosphere varies according to temperature and nearness to bodies of water.

Air always contains other substances besides these gases. For example, everywhere dust particles are found in air. In cities, gases from manufacturing plants, from motor cars, and from other sources mix with the air. Gases from volcanoes and oil wells mix with the surrounding air. However, the total volume of the atmosphere is so great and the volume of these gases is so small in comparison, that usually we are not aware of their presence.

The atmosphere, then, is a mixture of gases, of which nitrogen and oxygen make up about 99 per cent by volume.

Experiment 13. To show what part of the total volume of air is oxygen. (This experiment should be performed by the teacher.) Fill a battery jar with water (Fig. 29) to the depth of six inches. Float a small porcelain crucible on the water. In the crucible put a small quantity of red phosphorus. Ignite the phosphorus with a lighted splint or match. Immediately invert a large beaker over the crucible and lower it until the mouth of the beaker is below the surface of the water.

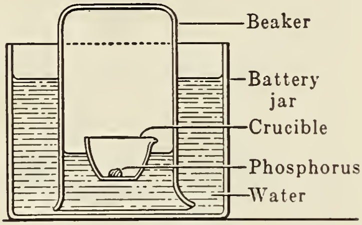


Fig. 29. Apparatus used to determine the approximate volume of oxygen in the air.

What is happening? When phosphorus burns, it combines with the oxygen in the air to form a white smoke. Why does the phosphorus stop burning? Allow the apparatus to stand for fifteen minutes. What happens to the white smoke? Has the water risen in the beaker? About what part of the whole volume of the beaker is now filled with water? What part of the whole volume of air originally in the beaker has been used up by the burning phosphorus? What part of the air, then, must be oxygen?

The burning phosphorus united with the oxygen of the air in the beaker, forming the white smoke which later dissolved in the water. As the oxygen was used up and the white smoke dissolved, the air pressure inside the beaker became less than the air pressure on the outside. Therefore, water was forced up into the beaker. If all of the oxygen is used up by the burning phosphorus, 21 per cent of the volume of air is used up. Thus, we may conclude that 21 per cent of the volume of air is oxygen.

What part of the atmosphere is nitrogen? If 21 per cent of the volume of air is oxygen, 79 per cent must be something else. Chemists have determined that of these remaining gases, all except one per cent is nitrogen; in other words, 78 per cent of the volume of air is nitrogen. The other one per cent of the volume of air is made up of gases called rare gases.

What are some of the uses of nitrogen? Nitrogen is an important part of certain foods necessary for all animals. It is also an essential plant food. In one form or another, nitrogen is necessary to all plant and animal life. Nitrogen is an essential part of ammonia, gunpowder, nitro-glycerine, and many other substances. The films used for motion pictures contain a large percentage of nitrogen. Since the air is four-fifths nitrogen and only one-fifth oxygen, we may say that nitrogen dilutes the oxygen which is taken into the lungs in breathing. This nitrogen cannot be used by the body and is therefore exhaled. All animal life is adjusted to this mixture of gases in the air and any marked change in the mixture would be injurious to health.

Rare gases in the atmosphere. One per cent of air, as you have already learned, is made up largely of rare gases. Name the five rare gases. They are colorless, odorless, and tasteless. Because they do not unite with other substances, special uses have been found for these gases. Helium is used in balloons and airships because it will not burn and still is lighter than most other gases. It is replacing hydrogen for this purpose, since hydrogen burns very readily and therefore is dangerous. Argon is used to fill some kinds of electric light bulbs. Neon is widely used in electric signs. The discovery of the rare gases and the uses which are made of them industrially are among the outstanding achievements of modern scientists.

Experiment 14. To show that the atmosphere contains carbon dioxide. Fill a small, clean beaker about half full of clear limewater. Place the beaker where it will not be disturbed. After a few hours shake the beaker gently. What do you see on the surface of the limewater? Scientists have proved that this substance has been formed by the action of carbon dioxide upon the lime in the water. Where must the carbon dioxide have come from?

Experiment 15. To show that carbon dioxide is exhaled in breathing. Fill a small, clean beaker about half full of limewater. Take a deep breath and exhale slowly through a glass tube into the limewater. Continue to exhale your breath through the limewater until it becomes milky. What caused this change? Where did the carbon dioxide come from?

The exhaled breath of a cat, dog, cow, horse, or other animal would cause this change, also. What gas then is given off when animals exhale?

Carbon dioxide in the atmosphere. The amount of carbon dioxide in the atmosphere is always about the same (Fig. 30).

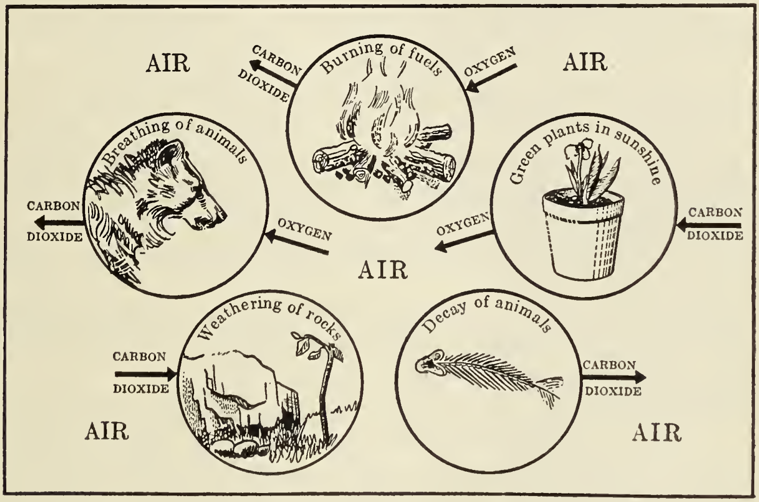


FIG. 30. The processes indicated above tend to keep the amount of carbon dioxide in the air nearly the same at all times.

Carbon dioxide is given off by the breathing of people and animals, the burning of fuels, the decay of various substances, and the fermentation of fruits and vegetables. On the other hand, carbon dioxide is taken out of the air during the hours of sunlight by the leaves of green plants. Another process which removes large quantities of carbon dioxide from the air is the weathering of rocks, which is explained on pages 214–15. By these processes, the amount of carbon dioxide given off into the air and the amount taken out of the air are so evenly balanced that successive samples of air taken from above fields in the open country always show the same per cent of carbon dioxide.

Uses of carbon dioxide. Do you know why a bottle of soda water "pops" when the cap is removed, and why the liquid bubbles and foams? It may seem strange that the answer to both these questions is "compressed carbon dioxide." Because the gas is slightly compressed in the soda water when it is bottled, it escapes with a "pop" when the cap is removed, and the excess gas expands and forms bubbles, causing the liquid to foam. The gas gives the liquid a slightly sour taste, which to some people is very agreeable. Many tons of carbon dioxide gas are used every year in the manufacture of soda water.

Do you know why yeast is used to make bread "rise"? Yeast is made up of millions of very small growing plants. When it is mixed into bread dough, the growing yeast plants are distributed throughout the dough. As these plants grow, the bubbles of carbon dioxide that are formed push their way through the dough. The volume of the dough thus increases, and we say the dough has "risen."

Baking powder and baking soda if used with cream of tartar or sour milk produce carbon dioxide when mixed into dough. This carbon dioxide makes the dough "light." Why?

Within recent years, uses have been found for carbon dioxide in the solid form known as "dry ice." It is so called because it passes directly from the solid form into carbon dioxide gas. Because it is dry, it can be packed in paper containers. Why would it be more convenient than ice in packing ice cream? The uses for "dry ice" are increasing in number. At the present time its main use is to keep foods from spoiling during transportation; naturally, it cannot be used to preserve foods that are harmed by freezing.

For years, carbon dioxide has been used to extinguish fires. There are two reasons for this: (1) it will not burn; and (2) it is heavier than air—that is, carbon dioxide gas can be poured over a fire, thus pushing away from the fire the oxygen necessary to keep the fire burning.

Experiment 16. To make a fire extinguisher. Arrange apparatus as shown in Figure 31. Fill test tube *A* two-thirds full of dilute sulfuric acid. Pour a solution of baking soda and water into bottle *B* until it is about two-thirds full. Invert bottle *B* and play the hose over a small fire built in a sink. What happens in the bottle? What happens to the fire? (Caution: The stopper must be held in place firmly during this experiment or the pressure of the gas formed will force it out. Also, some means should be used to protect your clothing in case the stopper is forced out of the bottle.)

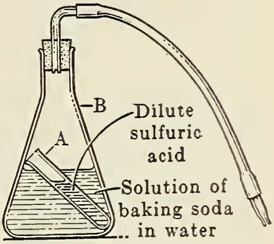


FIG. 31. A laboratory fire extinguisher.

What liquid fills tube *A*? Bottle *B*? The action of the sulfuric acid on the soda solution produced carbon dioxide gas which escaped through the tube and put out the fire.

Figure 32 shows a commercial *fire extinguisher*. Notice that the same materials are used as in the extinguisher you made. How would you start the operation of this fire extinguisher?

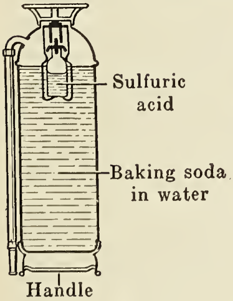


FIG. 32. Is there a fire extinguisher like this hanging on a wall of your school? What must be done to operate it?

Experiment 17. To show that air contains water vapor. Place a few lumps of calcium chloride on a watch glass and expose it to the air. Examine after a few hours. What has happened? Where did the water come from?

Water vapor in the atmosphere. Certain everyday experiences furnish additional evidence that the atmosphere contains water vapor. When water is spilled, it dries up. Where does it go? Sometimes in summer, droplets of moisture collect on the outside of a glass of ice water. Where does the moisture come from? During a dry summer, ponds, creeks, and streams may dry up. Where does the water go? Such common observations as these are convincing evidence that water is continually passing into the air. This change of water to water vapor is called *evaporation*. The formation of rain, dew, frost, and snow takes water vapor from the air. This change of water vapor to a liquid or solid form is called *condensation*. These two processes, evaporation and condensation, are going on all the time.

PROBLEM: WHAT GAS IN THE AIR IS NECESSARY IN OXIDATION AND COMBUSTION?

Oxygen in the solid and liquid parts of the earth. As you have learned, oxygen forms 21 per cent of the volume of the air. It is estimated that oxygen makes up almost 50 per cent of the total weight of the solid part of the earth's crust. United with hydrogen it forms eight-ninths of the weight of water. United with carbon, hydrogen, and a few other elements, oxygen forms about 65 per cent of the weight of the human body. Oxygen united with silicon forms such substances as quartz, opal, sand, sandstone, and agate. Whole mountains are composed of quartz. We see, then, that of all the substances which make up the earth, oxygen is the most abundant.

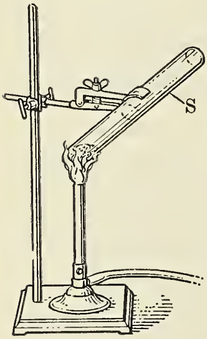


FIG. 33. Apparatus used for preparing a small quantity of oxygen.

Experiment 18. To prepare oxygen. Set up apparatus as shown in Figure 33. Mix a little potassium chlorate and one-fourth as much manganese dioxide. Put the mixture in a hard glass test tube *S*. Heat the test tube gradually. Oxygen is formed and is given off as the heating continues. Determine the color, odor, and taste of the oxygen.

Thrust a glowing splint into the test tube. What happens? Whenever a glowing splint is thrust into an odorless gas and the glowing splint bursts into flame, the gas is known to be oxygen. This is a test for oxygen. Keep on thrusting the glowing splint into the test tube as long as any change occurs. How does the way the splint burns in oxygen compare with the way it burns in air?

What is combustion (burning)? For many centuries the true explanation of burning was unknown. About the time of our Revolutionary War, oxygen was discovered by an Englishman named Priestley and by a Swedish chemist, Scheele. About the same time Lavoisier, a French scientist, not only discovered oxygen but also discoverd that when a substance burns, it unites with oxygen. *Combustion* (burning), then, is the union of a substance with oxygen, accompanied by heat and light. A combustible substance is one that will burn. This was a remarkable scientific discovery—one which helped greatly to solve other problems, as you will learn.

It was also discovered at this time that, when a substance burns, the total weight of the material formed is greater than the weight of the substance burned. It was proved that this additional weight was due to the union of oxygen with the substance burned. For instance, a pound of carbon in burning unites with two and two-thirds pounds of oxygen; that is, the products formed from the burning weigh three and two-thirds pounds. When coal is burned in a furnace, one of the products of the combustion is the gas carbon dioxide. It passes out of the chimney.

Experiment 19. To show what two products are given off when common fuels burn. (a) Light an alcohol lamp or a Bunsen burner. Invert a clean, dry, wide-mouthed bottle (Fig. 34) over the flame for about fifteen seconds. (The bottle may crack if the flame touches the glass.) Notice the moisture that forms on the inside of the bottle. Where did it come from? Remove the bottle from the flame. What happens to the moisture? Explain.

Repeat the experiment several times, using a clean, dry bottle each time. Are you convinced that water vapor is given off when gas or alcohol burns?

(b) Again invert a clean, dry, wide-mouthed bottle over the flame. Remove the bottle after fifteen seconds, turn it right side up and quickly pour a small amount of clear limewater into it, and cover it with the hand or a glass plate. Shake vigorously for a minute. What is the appearance of the limewater now? Does its appearance prove the presence of carbon dioxide gas? Why?

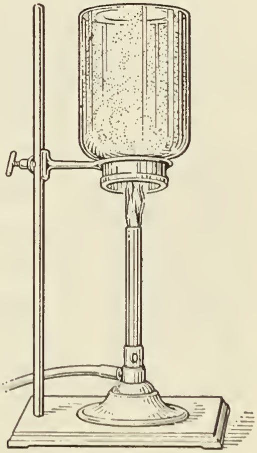


FIG. 34. This flame gives off water and carbon dioxide. Explain.

If this experiment is carried out with a candle, or with a wood or a coal flame, the results will be the same. When a substance like alcohol, gas, coal, or wood burns, it unites with oxygen and gives off water vapor and carbon dioxide.

What are the factors necessary for combustion? Experiment 19 shows that the factors necessary for combustion are: (1) a combustible substance, (2) oxygen, and (3) a temperature high enough to cause the substance to burn, that is, a *kindling temperature.* What was the combustible substance in Experiment 19? What gas from the air united with the combustible substance? How was the combustible substance raised to its kindling temperature?

Experiment 20. To show that different substances have different kindling temperatures. Place a six-inch square of sheet tin (or a tin lid) on a ring stand over an unlighted Bunsen burner. Locate the point on the tin sheet that is directly over the burner. At equal distances from this point place small pieces of red phosphorus, coal, wood, and paper. Light the Bunsen burner and regulate the gas so that the tip of the flame touches the tin. Observe the combustible substances carefully. Do they all start to burn at the same time? If not, note the order in which they do. Which has the lowest kindling temperature? The highest?

What is oxidation? No doubt you know that iron rusts. On the other hand, did you realize that, when iron rusts, it unites with oxygen from the air?

Experiment 21. To show that a gas is taken from the air when iron rusts. Pour water into a 200-cc. flask and shake until the inside of the flask is wet. Pour out the water. Put some iron filings into the wet flask. Shake the flask until the inside is coated with the iron filings? Invert the flask in a beaker of water (Fig. 35) and let it remain there overnight. Examine sometime during the next day. What would you say has happened to the iron filings? Has the water risen in the flask? Can you suggest a reason? Scientists have proved that this change in the filings was caused by the uniting of oxygen with the iron. Where did the oxygen come from?

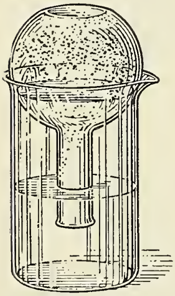


FIG. 35. The iron rusting on the inside of the flask takes oxygen from the air.

In this experiment the iron filings are said to have oxidized, or rusted. When a substance oxidizes, it unites with oxygen. Oxidation is defined as the union of a substance with oxygen. Oxidation always produces heat. The rotting or decaying of wood is also oxidation. When wood rots, oxidation is very slow, consequently heat is produced so slowly that it is not noticeable. As you know, when oxidation takes place so rapidly that the heat given off causes particles of the substance oxidized to glow, it is called combustion.

Oxidation takes place everywhere about us. The rotting of apples and the decaying of foods are common examples of oxidation. The heat of the body is produced by oxidation. Oxygen from the air is taken into the body through the lungs. Carbon is taken in as part of food. The blood brings the oxygen and carbon together. When they unite, the carbon is oxidized to carbon dioxide and the heat needed by the body is furnished by this oxidation.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

argon
calcium chloride
carbon dioxide
combustion
condensation
evaporation
fire extinguisher
kindling temperature
Lavoisier
lime water
mixture
neon
nitrogen
oxidation
oxygen
phosphorus
potassium chlorate
sulfuric acid

Write the number of each item on your paper and after it the word that completes the statement.

1. Twenty-one per cent of the volume of air is __________.
2. __________ is replacing hydrogen for inflating balloons and airships.
3. When carbon in coal unites with oxygen __________ is formed.
4. The burning of coal is an example of __________.
5. The rusting of iron is an example of __________.
6. Carbon dioxide turns __________ milky.
7. __________ will cause a glowing splint to burst into flame.

Which item in each of the following lists does not belong with the others?

8. oxidation; heat; decay; oxygen; nitrogen.
9. oxidation; condensation; evaporation; air; water.
10. Lavoisier; Torricelli; Priestley; oxygen; combustion.

Which of these statements are true? If any are false, re-state them in correct form.

11. When a substance burns, the products formed weigh less than the original substance.
12. Oxidation is always accompanied by light.
13. The air is a compound composed of gases.
14. The kindling temperature of a substance is the temperature at which it begins to burn.
15. Burning substances take oxygen from the air.

THOUGHT EXERCISES FOR UNIT I

Principles of Science

State the principles of science in this unit in sentence form. One of them is: As the distance above sea level increases, air pressure decreases.

Questions or Problems

1. Name four gases found in air. Give one use for each gas.
2. Why is a change of water vapor into rain, hail, snow, and frost known as condensation?
3. How does condensation differ from evaporation?
4. If a clean bottle were filled with oxygen, could you see the oxygen? Why? Could you tell whether the bottle contained oxygen? How?
5. When a fire is burning what changes are taking place in the surrounding air?
6. When animals breathe what changes are made in the air?
7. Why do papers rise from the ground after the passing of a rapidly moving car?
8. In a lift pump, what opens the lower valve? What closes it?
9. Sometimes window posters are held up by pressing a rubber cup against the glass. Explain.

Projects and Reports

1. Study the operation of the windshield cleaner on your car. If it is not run by electricity, study and explain in detail how it operates. Is the windshield cleaner connected in any way with the engine?

2. Investigate and make a list of the uses of compressed air in your community.

3. Visit a fire station and investigate the kind of water pump used to put out fires. How is it possible to throw a steady stream of water?

4. If you have at home your own private water system, tell how water is brought from its source into the house and how it is forced into the different rooms.

5. If a store or office building in your community uses a pneumatic system to transport money and business slips, study the system if you can get permission, and report to your class. Explain fully what makes the carriers move.

6. Read the life of Joseph Priestley and report to class. Show how his discoveries are related to the subject matter of this unit.

References for Reading and Study

1. Archibald, Douglas, *The Story of the Earth's Atmosphere.* D. Appleton-Century Company.
2. Darrow, Floyd L., *Thinkers and Doers,* Chapter XV. Silver Burdett Company.
3. George, Lloyd, and Gilman, James, *Air, Men, and Wings.* Robert M. McBride and Company.
4. Glassman, Don, *Tales of the Caterpillar Club. Jump!* Simon and Schuster, New York.
5. Holden, E. S., *Real Things in Nature.* The Macmillan Company.
6. Houston, E. J., *The Wonder Book of the Atmosphere.* F. A. Stokes Company.
7. Lay, Beirne, Jr., *I Wanted Wings.* Harper & Brothers.
8. Meister, Morris, *Water and Air,* Chaps. VII to XII. Charles Scribner's Sons.
9. Williamson, Thomas R., *Opening Davy Jones's Locker.* Houghton Mifflin Company.

UNIT II

WHAT IS SOUND AND WHAT USE DOES MAN MAKE OF IT?

Exploring the World of Sound

You may recall from your study of the early history of our country how a hunter in the woods would listen intently for the slightest sound. It might have been the snap of a twig, the imitated call of a bird, or the howl of a wolf. By such sounds, the hunter was able to tell whether he was in danger from treacherous enemies or wild animals. In our own time, the sound of a fire siren, the horn of an automobile, or a cry of distress may warn you of danger. On the other hand, the ringing of the telephone may bring you joy when you recognize the voice of a friend. You may get great pleasure when you listen to the playing of a musical instrument or an orchestra.

Have you ever thought how much our social and industrial life depend upon sound? In the business world sound is used in many ways. Letters are dictated; bells are used to direct employees; telephones are employed to place orders with people not at hand. Sound makes it possible to talk and to hear the voices of other people and to protect ourselves from danger. Many of our pleasures depend entirely or in part on sound. Because of it, we hear music and enjoy the radio. Our enjoyment of moving pictures has been greatly increased by the use of sound. Indeed, many of our most useful modern inventions depend upon sound for their successful operation.

These illustrations of sound are all very familiar to you. But have you ever wondered how the sound of the breaking twig reached the ears of the hunter? Have you wondered why you can hear music and how sounds are carried from place to place?

In Unit I, you learned that the air is an immense gaseous ocean which completely covers the surface of the earth to a depth of many miles. In this unit, you will learn that this great gaseous ocean in which we live makes it possible for us to hear sound.

CHAPTER V

HOW ARE SOUND AND MUSIC PRODUCED AND HEARD?

Do you know:

That if a bell is placed in a vacuum you cannot hear it ring? What happens to the air when you strike a note on the piano? That sound is caused by a "splash" in the air which makes waves?

Why a flash of lightning is seen before the thunder is heard? That water carries sound more rapidly than air? How rapidly iron carries sound? What an echo is? How sound is used to measure ocean depths?

How music differs from noise? How a phonograph produces sound? How talking pictures are made? Why all the strings on a violin are not the same size? How sounds are produced in your throat? How your ear picks up sounds from the air?

PROBLEM: WHAT PRODUCES SOUND AND HOW IS IT TRANSMITTED TO THE EAR?

Experiment 22. To show that air carries sound. Set up the apparatus shown in Figure 36. Connect it with an exhaust pump. Ring the bell and listen to the sound. Then remove air from the bell jar with the exhaust pump and ring the bell again. Is the sound louder or fainter than before? While the bell is ringing, allow air to enter the bell jar. What is the effect upon the loudness of the sound? Do you conclude from this experiment that sound is carried by air? Why?

If a perfect vacuum had been created in the bell jar, would you have been able to hear the bell ring? Why?

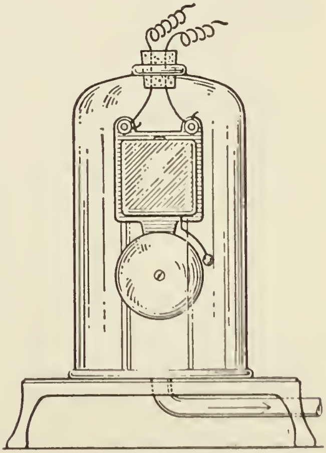


FIG. 36. As air is withdrawn from the bell jar the sound of the bell becomes fainter and fainter.

LIBRARY OF THE UNIVERSITY
OF ALBERTA

Experiment 23. To show that certain substances may be made to produce sounds. (a) Stretch a thin rubber band as shown in Figure 37; pluck one of the strands and listen intently. What do you hear? Pluck each strand several times. Listen to the sound each strand produces. What causes the sound? Keeping Experiment 22 in mind, tell what carried the sound from the rubber band to your ear.

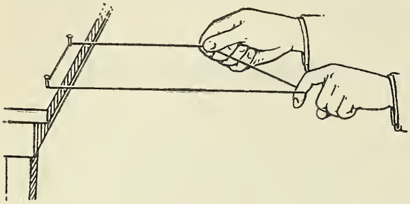


FIG. 37. A sound is produced by a vibrating substance.

(b) Strike a tuning fork on the heel of your shoe; then hold the prongs near your ear. What do you hear? Strike the tuning fork again and hold the base of the fork on a desk or table. What do you hear this time? What caused these sounds? How does the second sound differ from the first? Can you suggest a reason? What carried the sound from the tuning fork to your ear? Name several other materials that may be made to produce sound.

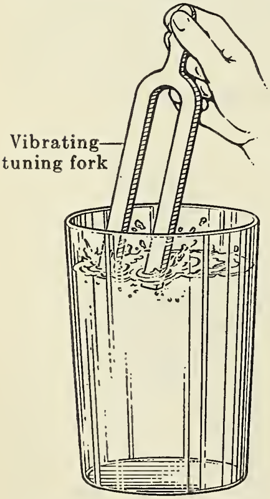


FIG. 38. One way of showing that a tuning fork moves back and forth (vibrates) when it produces sound.

Experiment 24. To show how a substance produces sound. (a) Fill a glass with water. Strike a tuning fork and touch the surface of the water with the prongs (Fig. 38). What happens to the water? What caused the water to be disturbed? What were the prongs doing when they produced sound?

(b) Suspend a pith ball (Fig. 39) so that it touches one prong of a tuning fork mounted on a base. Strike the tuning fork. What happens to the pith ball? What caused the pith ball to fly away from the tuning fork? What were the prongs doing when they produced sound? From this experiment what do you conclude the prongs of the tuning fork must do to produce sound?

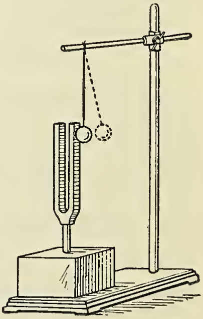


FIG. 39. Another way of showing that a tuning fork vibrates when it produces sound.

A vibrating substance produces sound. The preceding experiments show that the substances producing a sound were in rapid motion. The strands of the rubber band, also the prongs of the tuning fork, were moving back and forth rapidly while they were producing sound. This back and forth motion of a substance is called *vibration.* When a substance is producing sound, it is vibrating. The strings of a violin are set in vibration by means of a bow. A reed in the mouthpiece of a saxophone is set in vibration by a player's breath. The sounds made by wind instruments like the pipe organ are produced by vibrating columns of air. Any sound, no matter how it is produced, is caused by a vibrating substance.

What are sound waves? When the prongs of a tuning fork vibrate, they produce vibrations in the air; i.e., they set up back and forth movements in the air that correspond to the back and forth movements of the prongs of the tuning fork. As the vibrating prongs strike the air, they push on it and thereby compress it. This compressing of a layer of air permits a layer of air just back of it to expand and therefore become less dense; thus a layer of compressed (denser) air is followed by a layer of rarer (less dense) air. Layers of compressed air and rare air follow one another (Fig. 40). They are called sound waves. *A sound wave* consists of a compressed layer of air and the rare layer which is immediately after it.

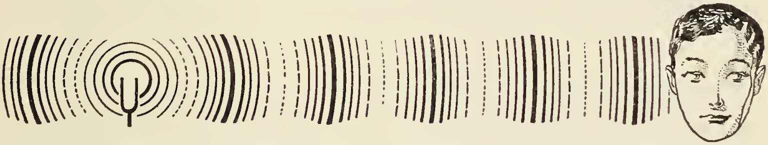


FIG. 40. Diagram representing a sound wave. The dark rings represent layers of compressed air; the light rings represent layers of air less dense than air usually is.

How do sound waves move through the air? In Experiment 22 you learned that sound is carried by air. Sound waves travel in the air in a manner somewhat similar to the way water waves travel from a point of disturbance (Fig. 41). As you may have observed, when a stone is dropped into still water, waves move outward from the point of disturbance in the form of ever-enlarging circles; sound waves in air, on the other hand, travel in all directions from a vibrating substance in ever-enlarging spherical layers. (The cover of a baseball is an example of a spherical layer.) The fact that a sound may be heard in all directions from its source tends to show that sound waves travel outward from their source in the form of spherical layers. Figure 42 shows the way in which sound waves travel.

As a sound wave travels, the air vibrates but it does not travel with the sound wave. As you have already learned, when a sound-producing substance, such as a tuning fork, begins to vibrate, the layer of air next to the tuning fork is compressed. As this layer expands, it compresses a second layer of air, and so on. As a result the volume of air affected is composed of alternating layers of compressed and rare air. The compression and rarefaction move forward, but at a given point the air merely vibrates back and forth just as the prongs of the tuning fork do.

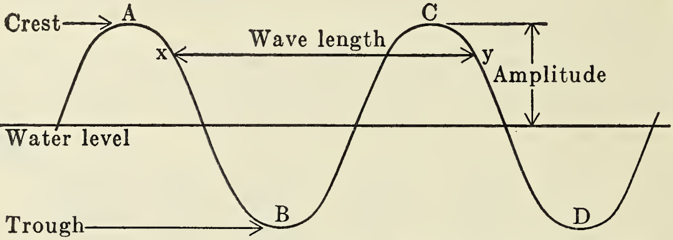
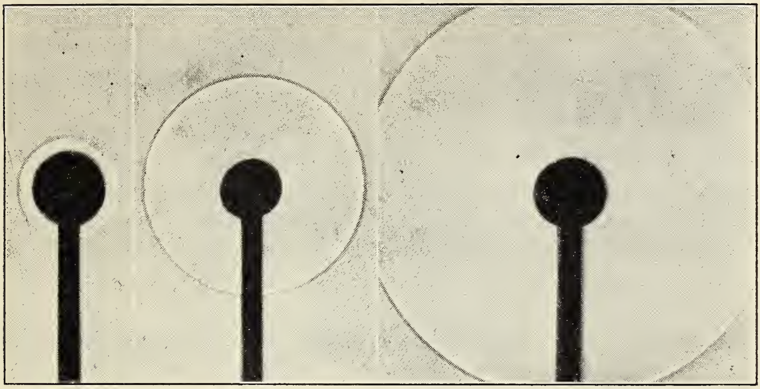


Fig. 41. The distance from a point on one wave to the corresponding point on the next wave is the length of a wave. The number of waves that pass a given point per second is the *wave frequency*. Define, for water waves, the terms *crest*, *trough*, *amplitude*, and *water level*.

To help you understand how a compression and rarefaction travels without the air itself traveling, place a piece of cork on water in a tub. Drop a small stone into the water to set up waves. Note that the waves move away from the place where the stone was dropped, but that the piece of cork does not move with the waves; it merely bobs up and down. The water wave travels but the water itself merely moves up and down.



Courtesy Dr. A. L. Foley

FIG. 42. At the left is a photograph of a sound wave produced by an electric spark at the dark spot in the center; the center photograph was made .0001 second after the spark was produced; the one on the right .0001 second after the center one.

If a tub of water is not available, tie one end of a piece of rope to a desk and hold the other end so that the rope is slack. By moving your hand up and down waves are produced which travel along the rope. Mark any point on the rope and notice that, although the wave travels along the rope, the marked point merely moves up and down.

As a sound wave moves farther and farther from its source, a larger and larger volume of air vibrates; consequently the sound becomes fainter. Finally the air vibrations become so weak that they cannot be heard.

How fast does sound travel? When a gun is fired at a distance of several hundred yards from an observer, he first sees the smoke and then hears the report. When a distant locomotive whistles, the steam from the whistle is seen a few seconds before the sound of the whistle is heard. Likewise, a flash of lightning is seen before the sound of thunder reaches us. Do these illustrations show that time is required for sound to travel?

Experiments show that the speed of sound in dry air at 0° C. is about 1087 feet per second; this speed increases slightly as the temperature rises.

Do other substances besides air transmit sound? On page 57, read the topic "How sound is used to measure ocean depths." What carried the sound wave from the ship to the bottom of the ocean and back to the ship?

Experiment 25. To show that other substances besides air carry sound. (a) Place a pocket watch on the top of a large wooden table. Put your ear against the table top at some distance from the watch. Listen carefully. Can you hear the watch tick? Put your ear at different places on the table top. How far from the watch can you hear it tick? What carried the sound from the watch to your ear? Remove the watch from the table and have someone hold it. Stand so that your ear is at a distance from the watch equal to the farthest distance at which you heard it tick when it lay on the table. Listen carefully. Can you hear the watch tick? What does this experiment tell you about wood as a conductor of sound?

(b) Have someone hold a watch against a gas or water pipe. Hold your ear against the pipe at some distance from the watch. Listen carefully. Can you hear the watch tick? How far from the watch can you hear it tick? Remove the watch from the gas or water pipe and have someone hold it. Stand so that your ear is at a distance from the watch equal to the greatest distance at which you heard it tick when it lay against the pipe. Can you hear the watch tick? What does this experiment tell you about iron as a conductor of sound?

Water, wood, and iron are all good conductors of sound. In fact, each one is a better conductor of sound than air. In water, sound travels 4.3 times as fast as in air; and in steel wire, 15 times as fast as in air.

Can sound be reflected? From your past experience you know that light can be reflected by a mirror or any other object which has a very smooth or highly polished surface. Those of you who live in a city undoubtedly have noticed that sunlight reflected from a nearby window may brighten a room in your home almost as well as if the sun were shining directly into it. In somewhat the same way as light is reflected sound can be reflected. Most hard surfaces are good reflectors of sound. However, the reflecting surface need not be smooth or highly polished. Even the side of a hill will reflect sound.

Special problem. The reflection of sound can be shown by the following procedure. Make two long tubes by wrapping heavy paper loosely around a broomstick. Paste the paper so that it will not unwrap. Then remove the broomstick. Label the ends of one tube A and B and the ends of the other tube C and D. Place the tubes on a table so that the ends A and C are about two or three inches apart and so that the tubes form a right angle (Fig. 43). At end D place a pocket watch. Hold your ear at end C. Can you hear the watch tick? Hold your ear at end B. Can you hear the watch tick? Stand a book on end near the ends A and C so that the flat side of the book makes a 45° angle with the tube AB and the same angle with the tube CD. Again hold your ear near end B. Did the book cause the sound of the watch to be louder at end B? If not, change the angle of the book slightly. Did the book reflect the sound? Can you think of another way of proving that sound can be reflected?

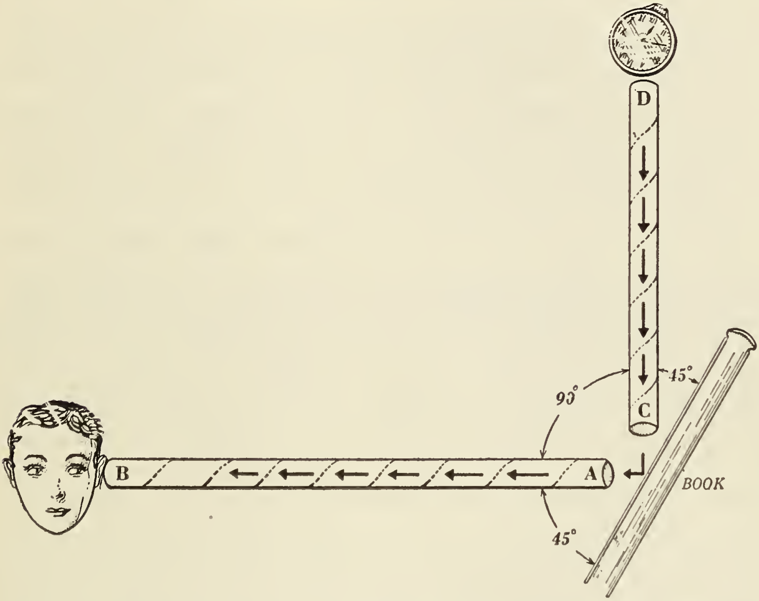


Fig. 43. Apparatus used to determine whether sound can be reflected.

What is an echo? If you have ever stood about a quarter of a mile from a large building, a hill, or a high cliff and shouted, you may have heard the sound of your voice come back to you. When sound waves strike such an obstruction, they are thrown back (reflected) toward their source where they may be heard again. The repetition of a sound caused by the reflection of sound waves is called an *echo.*

Can echoes interfere with distinct hearing? In some auditoriums it is difficult to hear the speakers because of echoes. If the walls of the auditorium are hard and bare, the sound waves produced by the voice of a speaker may be reflected from the walls. If they are, a person in the audience may hear the echo of one word at the same time that he hears the sound of another word that came directly from the speaker. This causes a confusion of sounds which makes hearing difficult. Echoes may be largely overcome by covering the walls with soft material, so that sound waves will not be reflected.

Have you ever been in a large auditorium where draperies hung on the walls? Why were they hung there? Why are there fewer echoes in an auditorium filled with people than when it is empty?

How sound is used to measure ocean depths. In 1920 the "echo" method was first used in measuring very deep places in the ocean—a problem which had always presented great difficulties. With this method sound waves are directed to the bottom of the ocean, where they are reflected to the surface. The time is measured accurately from the instant the sound wave leaves the surface of the water until it returns to the surface. Since the speed of sound in water is known, the distance the sound traveled (i.e., the distance to the bottom of the ocean and back again) can be calculated. By this method, ocean and harbor depths are measured and sunken ships located.

PROBLEM: WHAT KINDS OF VIBRATIONS PRODUCE MUSICAL TONES?

What is a musical tone and what is a noise? In Experiment 23 the sound produced by the tuning fork is called a musical tone. If the tuning fork used was one which corresponded to middle C on a piano, 256 vibrations were set up in the air each second. If the sound caused by the tuning fork continued for some time, 256 vibrations reached the ear each second. Such vibrations are called regular vibrations. They are pleasing to the ear and we recognize them as a musical tone.

Contrast with this the vibrations which come to the ear from a heavy truck loaded with empty tin cans passing over a rough pavement. Such vibrations are irregular vibrations. They are not pleasing to the ear and are recognized as noise. Regular vibrations produce musical tones; irregular vibrations produce noise.

The human ear is not able to hear all vibrations. Those at the rate of less than 16 per second and of more than 35,000 per second cannot be heard by most people. Musical tones, then, are produced by regular vibrations ranging from 16 per second to 35,000 per second. Noises are produced by irregular vibrations within the same range. The exact range of vibrations heard depends upon the individual ear.

Experiment 26. To show how tones are produced by stringed instruments. Bring to class a violin, guitar, or other stringed musical instrument. Examine the strings. Are they all of the same diameter? All of the same length? Pluck each string. Which string produces the highest tone? The lowest? The highness or lowness of a musical tone is called *pitch.* The pitch of a tone is determined by the number of vibrations per second which produce it.

What is the relation between the pitch of a tone produced by a string and the diameter of the string?

Pluck one of the smaller strings again and note its pitch. Shorten the string by pressing it against the finger board with your finger. Pluck the shortened string and note its pitch. How does shortening a string affect its pitch? Lengthen the string by moving your finger. How does lengthening a string affect its pitch?

Pluck the same string again and note its pitch. Tighten the string, then pluck it again and note its pitch. How does tightening the string (increasing its *tension*) affect its pitch? Loosen the string (decreasing its tension). How does loosening the string affect its pitch?

These experiments show how the pitch of a tone produced by a vibrating string depends upon the length, diameter, and tension of the string.

If two strings are of equal length and equal tension but unequal in diameter, the pitch of the tone produced by the string with the smaller diameter will be the higher.

If two strings are of equal length and equal diameter but unequal in tension, the pitch of the tone produced by the string with the greater tension will be the higher.

If two strings are of equal diameter and equal tension but unequal in length, the pitch of the tone produced by the shorter string will be the higher.

Tones of the same pitch may vary widely in quality. The quality of the tone (timbre) of a stringed musical instrument depends upon the material of which the strings and other parts of the instrument are made.

How are tones produced by musical instruments? We learned from Experiments 23 and 24 that sounds are produced by vibrating substances. But how are sounds made louder and given the quality that we recognize and enjoy as musical tone by different kinds of musical instruments?

In any stringed musical instrument the sounds may be and usually are made louder (reinforced) by a sounding box, such as the body of a violin or bass viol. In every stringed musical instrument, the source of the sound or music is the vibration of the strings. Can you explain now why in Experiment 23 the sound was louder when the base of the tuning fork was held on the table?

The music produced by percussion instruments—drums, cymbals, bells, and chimes—is caused by vibrating membranes, wood, or metal.

The music produced by a large class of musical instruments called wind instruments is caused by vibrating columns of air. A few examples are the horn, trumpet, clarinet, piccolo, saxophone, and pipe organ. In instruments such as the oboe, clarinet, and saxophone the column of air is set into vibration by a reed in the mouthpiece. In wind instruments a difference in pitch is produced by changing the length of the air column. The change in the length of the air column in a wind instrument produces the same result as changing the length of the string in a stringed instrument, the shorter the column, the higher the pitch. The shortening of the air column is accomplished by a special device in each kind of instrument. How is the length of the air column changed in a trombone? A cornet? In the cornet and the French horn a column of air is set into vibration by the vibrations of the lips of the player. A modern pipe organ is a complex musical instrument; for our work it is sufficient to know that most of its tones are produced by vibrating columns of air.

Experiment 27. To show how a phonograph produces sound. Place a phonograph record on the turntable and start it rotating. Place your finger nail in one of the grooves of the record and press very lightly. What do you hear? Can you recognize the tune? How does your finger nail move? What do you call this kind of motion? How is music produced by a phonograph?

Place the tone arm, with the needle attached, on the record and play the record. Place your finger on the diaphragm *A* (Fig. 44). What is the diaphragm doing?

How are phonograph records made? First a plain wax disk is made. On it a continuous groove is cut. When music or conversation is being recorded, the sound waves are directed toward a diaphragm which communicates its motion to a sharp instrument that makes impressions in the bottom of the groove. These impressions correspond to the vibrations of sounds that are being recorded.

When the record is played, the needle is set into vibration by the impressions in the groove. Since the needle is attached to the diaphragm *A* (Fig. 44), the diaphragm is in turn set into vibration. The air in the horn or the sounding box reinforces these vibrations and sends them out as spoken words or music. The phonograph record shows that in certain soft materials vibrations can be recorded as little elevations and depressions. These can be used to set up vibrations the same as the original ones.

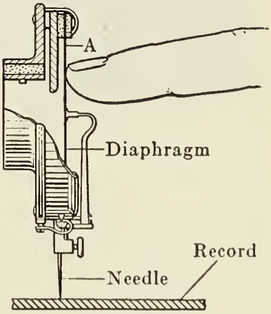
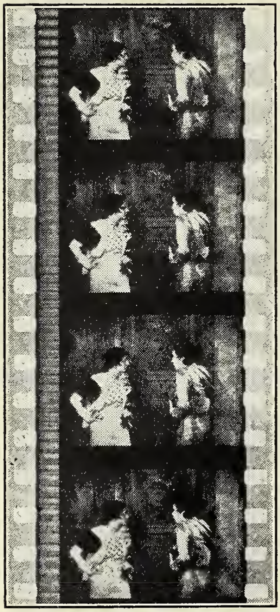


Fig. 44. What does the diaphragm do when a record is played?

In another type of record, grooves of uniform depth and width are so cut that the musical vibrations are recorded as a series of notches in the sides of the grooves. The notches correspond exactly to the vibrations which produce the music. When the record is played, the needle runs smoothly on the bottom of the groove but at the same time it is set into vibration by the notches in the sides of the groove. This motion of the needle causes the diaphragm to vibrate and to reproduce the original words or music.

In both types the original impression is cut in wax and then a metallic plate is made from the wax impression. From the metallic plate a large number of records can be made.



Courtesy Eastman Kodak Company

FIG. 45. A combined print of picture and sound track. Notice the light and dark lines in the sound track at the left. The light spots on either side are holes in which the sprocket wheel fits to move the film through the projector.

Sound movies. When scientists learned to use a phonograph with silent movies, the motion picture industry began to develop a device to produce sound movies. The dialogue or music for the sound movie was recorded on a phonograph disk. The movement of the phonograph disk was kept in step (synchronized) with the picture so that, when the lips of the actors were seen to be moving on the screen, the people in the audience actually heard the actors' voices through the loud-speaker. In the same way and at the same time the audience heard the music played by an orchestra which was shown on the screen.

This method of reproducing sound presented many difficulties due to the necessity of frequently changing records and patching broken film. Consequently a new method was soon developed, by which the sounds made by the voices of the actors or the music of an orchestra are recorded at one side of the picture film (Fig. 45).

You know that sound is produced by vibrations. In the movie studio the vibrations produced by the voices of the actors or the music of an orchestra operate a "flash lamp." As the picture is taken, these flashes of light from the "flash lamp" are photographed at one side of the film, at the same time that the picture is photographed. The film is then developed, and the sound vibrations appear as light and dark lines in the *sound track* on the picture film. When the finished film is run through the motion picture machine, the variations in the sound track are translated into the original sounds of the actors or the orchestra. These sounds and their accompanying pictures on the screen make up sound movies as we know them.

Problem: How Do the Organs of Speech Produce Sounds, and How Do the Organs of Hearing Receive Them?

How is the voice produced? Animals are able to produce sounds in their throats but so far as we know man alone possesses the gift of speech.

Like all other sounds, the voice is produced by a vibrating substance. In the voice box (larynx) at the entrance to the windpipe (trachea), there is a pair of membranes called the *vocal cords.* When sound is not being produced, the vocal cords are apart. When sound is being produced, the cords are drawn together and tightened by muscles. At the same time air from the lungs is forced between them, causing their edges to vibrate.

To illustrate the action of the vocal cords, blow through a glass tube over the end of which you have stretched a piece of rubber with a slit in it. The pitch of the sound may be varied by changing the tension of the rubber. Why?

Sounds produced by the vocal cords and modified by the shape of the mouth, throat, and nasal cavities and by the position of the tongue, become speech.

A cold in the throat inflames and thickens the vocal cords, thus often lowering the pitch of the voice.

How we hear. Figure 46 is a diagram of the human ear, showing the outer ear, the middle ear, and the inner ear.

The outer ear consists of an irregularly folded cartilage covered with skin. Because of its shape, the outer ear is especially well adapted for catching sound waves and conducting them through the auditory canal to the ear drum, the outer covering of the middle ear. The ear drum (tympanic membrane) is a thin, flexible membrane.

The middle ear is a small cavity lined with mucous membrane and connected by the eustachian tube with the throat (pharynx).

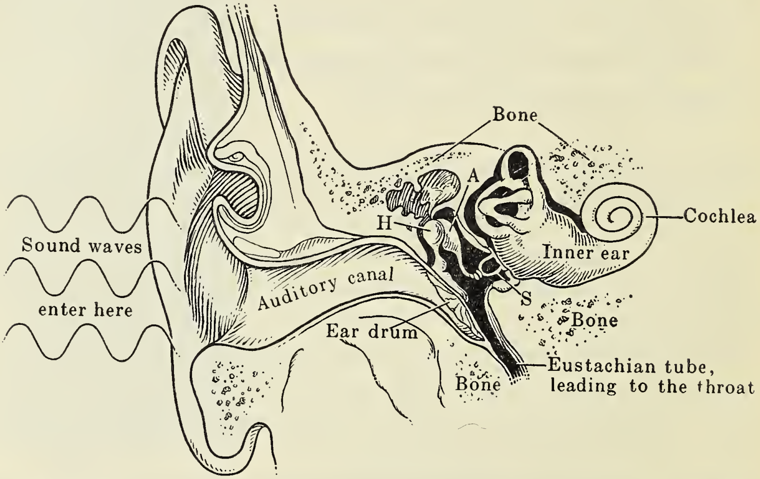


FIG. 46. Diagram of the human ear. With the help of the text, explain how the sound of a whistle finally reaches the nerves of hearing.

This part of the ear contains three bones, connected one with the other. The names of these bones, suggested by their shape, are the hammer (*H*), the anvil (*A*), and the stirrup (*S*). They extend from the ear drum to the membrane which closes the passage into the inner ear.

The inner ear is located in an irregular cavity in the bone behind the outer ear. It is composed mainly of a membranous sac filled with a liquid in which are tiny stones. The first part of the inner ear is called the vestibule. To the vestibule on one side is attached a tube coiled like a snail shell and called the cochlea, in which the fibers of the auditory nerve receive the vibrations caused by sound waves. Three semicircular canals, which seem to have something to do with balancing the body, are attached to the other side of the vestibule.

Suppose sound waves are coming from a vibrating violin string to the ear. They are caught by the outer ear and conducted through the auditory canal to the ear drum. The sound waves cause this membrane to vibrate in unison with the violin string, that is, just as many times per second as the string is vibrating. The ear drum causes the bones of the middle ear to vibrate, and they in turn pass the vibrations on to the liquids of the inner ear. These liquids distribute the vibrations to all parts of the inner ear so that they finally reach the fibers of the auditory nerve, through which the sound vibrations are sent to the brain. Here they are interpreted by the brain as sounds. How the brain translates these vibrations into sound we do not know.

How does noise affect us? Physicians have found that loud unexpected noises such as the blast of a whistle or an automobile horn, the crack of a gun, the screech of brakes or the scream of a child, injure the most sensitive part of the ear and that such noises increase the pulse rate, raise the blood pressure, cause irregularities in heart beat, disturb digestion, and increase pressure on the brain.

They have also found that noises such as the roar of traffic, the click of typewriters, the hum of machinery, the clatter of dishes, and the roar of motors wear on our nerves and exhaust our energy. As a result, our working efficiency is reduced. Since mental work is affected more by noise than by physical work, people who do mental work should have quiet surroundings when they work.

In certain cities in Europe and in America steps have been taken to lessen the noises caused by traffic, building and repair work, and radios. Horns on automobiles and trucks are allowed to be sounded only for safety. Hours for the collection of garbage and for making deliveries are regulated. Loud speakers and radios are not allowed to be turned on full blast. Rubber, felt, cork, and other sound insulating materials are being used in the construction of buildings, cars, trains, etc. in order to decrease noise and to better living conditions.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

auditory canal
cochlea
compression
conductor
diaphragm
echo
eustachian
larynx
membrane
musical tone
percussion
pharynx
phonograph
pitch
rarefaction
reflection
sonic altimeter
sound track
sound wave
synchronized
tension
trachea
transmit
tuning fork
vestibule
vibration
vocal cords

Write the number of each item on your paper and after it the word that completes the statement.

1. Sound is produced by a __________ substance.
2. Sound waves travel outward from a source in the form of __________.
3. At the temperature of freezing water, the speed of sound in air is __________ feet per second.
4. A sound wave travels __________ in water than in iron.
5. A sound wave travels __________ in water than in air.
6. Reflected sound is called an __________.
7. A musical tone is produced by __________ vibrations.

Which item in each of the following lists does not belong with the others?

8. compression; rarefaction; evaporation; sound wave; spherical layer.
9. sonic altimeter; ocean depths; echoes; airplane; whistle.
10. auditory canal; eustachian tube; auditory nerve; cochlea; optic nerve.

Which of these statements are true? If any are false, re-state them in correct form.

11. Sound waves can be heard in a vacuum.
12. Noise is produced by regular vibrations.
13. All vibrations which reach the ear are recognized as sound.
14. Sound is always carried by waves in the air.

THOUGHT EXERCISES FOR UNIT II

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Sound is produced by a vibrating substance.

Questions or Problems

1. Do all vibrating bodies produce sound?
2. How do sound waves differ from water waves?
3. How can the loudness of a sound be increased?
4. A cold in the throat may lower the normal pitch of the voice. Explain.
5. How does music differ from noise?
6. Name three ways in which the pitch of a string can be raised.
7. Name five musical instruments that produce sounds by a vibrating column of air.
8. Why are drapes hung on the walls of an auditorium? Explain.
9. A cannon was fired six miles away from an observer. How long did it take the sound to reach the observer?

Projects and Reports

1. Some persons believe it is possible to receive sound messages from Mars. Explain to the class how our present scientific knowledge leads us to conclude that such a belief is unsound.
2. How large must a room be before echoes can be heard?
3. Make a study of resonance and demonstrate it to the class.
4. Make a study of a musical instrument. Bring it to the class and explain the kind of instrument it is, and show how to change its pitch. Show how its construction provides for resonance.
5. Compare a sound and a water wave. Explain with the aid of drawings on the blackboard their likenesses and differences in form and movement. Label the parts of both kinds of waves.

References for Reading and Study

1. Bragg, W. H., *The World of Sound.* G. Bell and Sons, Ltd.
2. Jeans, Sir J. H., *Science and Music.* The Macmillan Company.
3. Meadowcroft, W. H., *Boy's Life of Edison.* Harper & Brothers.
4. Noise Abatement Commission, New York, *City Noise.*

UNIT III

WHAT IS WATER AND WHAT USE DOES MAN MAKE OF IT?

Exploring the Great "Oceans" of Water

Undoubtedly, almost every boy and girl enjoys swimming, canoeing, and rowing. Many young people who live near a river or lake look forward eagerly to the time when they can have an outboard motor to propel their canoe or boat swiftly through the water. A boat ride, whether in a small boat or on a steamship, is a great pleasure to most people. If the water is clear, to look down into its depths as the boat moves along fills one with wonder. Many questions arise in the mind of curious persons. Why does the boat float? What is water made of? Where does water come from? Why is it easier to swim when you keep all except a very small portion of your body under water? Why is certain water harmful to drink and other water harmless?

Those of you who live near large bodies of water or those who visit ports on lakes and oceans are accustomed to see huge steel vessels that weigh thousands of tons float on the water. You know that if several tons of steel bars were thrown into the water, they would sink at once. How is the steel ship different from the steel bars? Does the same force cause the ship to float that causes your body to float when you swim? Does water exert a force that causes certain bodies to float?

Water is said to dissolve more materials than any other known substance. It mingles so freely with other substances that it is scarcely possible to find pure water anywhere in nature. Some of the substances found in water render it unfit for people to drink. Cities usually have huge purification plants where these injurious substances are removed before it is used by the people.

An abundant supply of pure water is one of the necessities of civilized man. Early man was able to supply his needs by building his home near a spring, stream, or lake, or by digging a well. Today many people receive an abundant supply of pure water by turning on a faucet. Man's achievement in securing an abundant supply of pure water for his needs is one of the triumphs of science.

CHAPTER VI

WHY IS A SUPPLY OF PURE WATER NEEDED FOR OUR HOMES?

Do you know:

Why large cities spend millions of dollars to secure pure water for the use of their inhabitants? That the water you drink today may have been in the ocean a month ago? That clear, sparkling water may not be safe to drink? How impurities get into water? Why large cities have filtration plants? Why chlorine is put into drinking water? Why ammonia is put into drinking water?

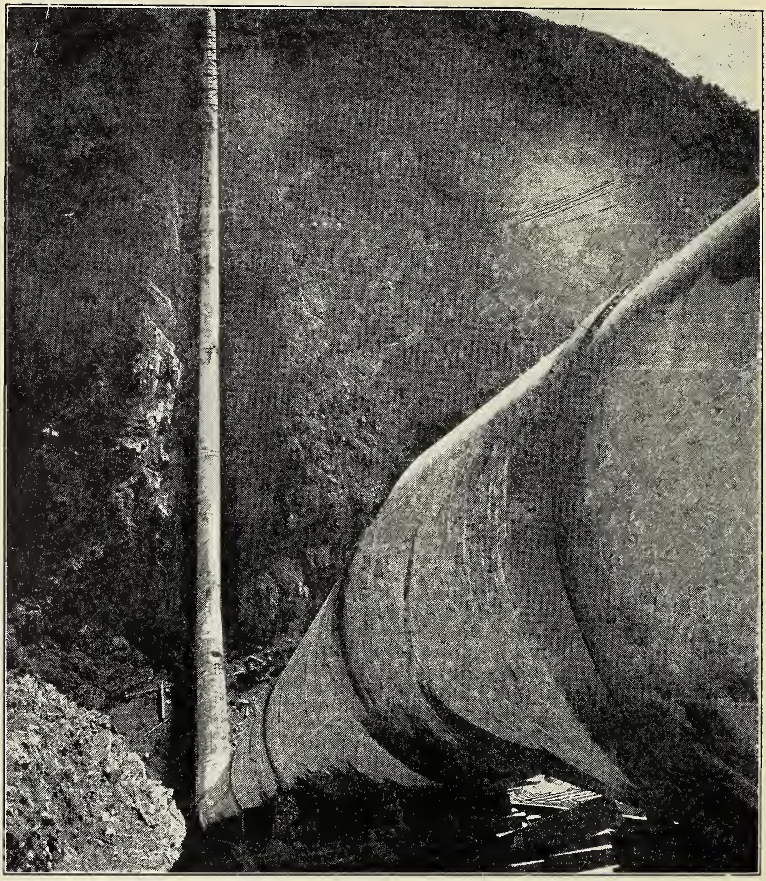
Why some water will not form soapsuds easily? Why washing soda is sometimes put into water? What causes scale to form on the inside of a teakettle?

What makes water rush out when you turn on a faucet? What kind of water supply system your community has? That sewage wastes can be changed into harmless liquids and solids? How water is measured?

PROBLEM: WHERE DO WE GET WATER FOR USE IN THE HOME?

Water is found not only in oceans, lakes, rivers, and streams, but also in most soil, and in other parts of the earth's crust. It exists as a vapor in the atmosphere. A large part of all living matter—plant and animal—consists of water. Water is necessary to all living things. Without it the most fertile soil becomes a desert where no plants can live; without it all animals die.

If we are to be healthy, we must have pure water to drink. Pure water for drinking purposes or domestic use is water that does not contain substances which cause sickness or give water a bad taste or odor. Water polluted with garbage, excretions from the body, and disease germs may cause sickness. Diseases, such as cholera, dysentery, and typhoid fever are usually caused from drinking impure water.



Courtesy Los Angeles Chamber of Commerce

FIG. 47. A "siphon" that supplies water to the city of Los Angeles from distant watersheds. The pipe is large enough to admit an automobile.

What are the sources of water for homes in the country? The problem of supplying homes with a sufficient amount of pure water is solved in many ways. In rural districts and in small villages, water is generally obtained from springs, wells or cisterns.

Early settlers who lived where no springs were to be found dug wells for water. If water could not be obtained by digging a well, a cistern was dug in which to store rain water that ran off the roofs. Sometimes water was pumped to a cistern or storage tank from a distant spring by means of a pump run by a windmill or by a pump called a hydraulic ram. More recently, deep drilled wells have come into use in rural districts. Water coming from such a well is apt to be free from impurities.

Where are the sources of drinking water for homes in cities? In cities the problem of furnishing pure water in sufficient quantity involves the expenditure of large sums of money and the services of many people. Perhaps the most famous water system in history was that of ancient Rome. The water which supplied the city was brought from the Apennine Mountains through great aqueducts. Cities in or near mountainous regions may still receive their water supplies through pipes from reservoirs which store up the water of mountain streams. New York and Los Angeles (Fig. 47) have each spent large sums of money in procuring a supply of pure water from uncontaminated sources on distant watersheds and mountains. Large cities on or near one of the Great Lakes obtain water from it by pumping water from intakes called "cribs." These cribs are located out in the lake, where the water is likely to be more free from sewage than it is near the shore. As a rule a city on or near a river obtains its water supply from rivers.

PROBLEM: HOW IS WATER PURIFIED FOR HOUSEHOLD USE?

Why must water be purified? We need only to glance at the water in some rivers to realize that water from such a source must be purified if it is to be used for household purposes. Streams flowing through coal-mining regions contain coal, dirt, and sulfur. The water in streams flowing through manufacturing cities and towns is apt to become impure even though care may be taken to keep it free from sewage and waste products from factories. Unfortunately, sewer systems of many cities empty into the rivers or lakes from which their own supply of drinking water is taken.

The appearance of water is no indication of its purity or impurity. Quite muddy water may be safe to drink, while clear and sparkling water may be unsafe. The latter may contain injurious materials in solution, such as poisonous alkali present in waters in some desert regions, or, more frequently, disease germs.

The contrast between the health conditions in two German cities, Hamburg and Altona, during a cholera epidemic shows that very different results were produced by the use of pure instead of impure water. Hamburg and Altona are located on opposite sides of the Elbe River, and both draw their water supply from it. In 1892 there were thousands of cases of cholera and hundreds of deaths in Hamburg. Across the river in Altona only a few persons contracted the disease. Investigation showed that they were persons who worked in Hamburg and while there drank the impure water. At that time the people of Altona were using filtered water. What do the experiences of these cities teach you about the purification of water?

Characteristics of pure water. One of the chief duties of officials in charge of the welfare of a community is to provide a supply of pure water for household use. The chief characteristics of water suitable for household use are: (1) a clear and sparkling appearance; (2) a high degree of purity, that is, freedom from all organic matter including disease germs (very small plants or animals that cause people to become sick); and (3) a pleasing taste.

As many towns and cities must get their water supply from streams and rivers of the kind already described, you may wonder how such water may be made suitable for household use. The following simple experiment will indicate the first step in this process.

Experiment 28. To show how muddy water may be made clear. Fill two wide-mouthed bottles nearly full of muddy water. Into one of them put a small amount of alum dissolved in water. Allow both bottles to stand where they may be observed. Do you notice any difference in the rate at which mud settles in the two bottles? In which bottle did the water first become clear? What conclusion do you draw from this experiment?

Use of alum in the purification of water. The preceding experiment shows that muddy water may be made clear rapidly by mixing alum with it. Alum causes the small particles of dirt suspended in the water to join together into larger particles. These larger particles quickly settle to the bottom. In a city water system quantities of alum are mixed with the water as it flows into large settling basins, where the larger and heavier particles settle rapidly to the bottom. Cities which draw their water supply from rivers flowing through coal regions have found that by this means water that is as black as ink may be made clear and sparkling.

How a filtration plant helps in the purification of water. There are certain substances, however, that will not settle to the bottom of a settling basin. The fact that fish and other animals live in water shows that the water may contain organic matter (i.e., either living or dead plants and animals). This organic matter is objectionable in drinking water and sometimes positively harmful, since it may contain disease germs. Organic matter may be removed by filtration; therefore modern filtration plants are maintained by most cities to assist in the purification of water.

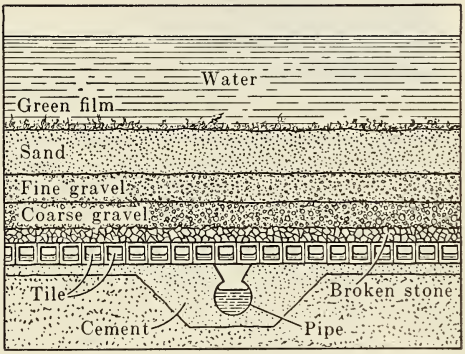
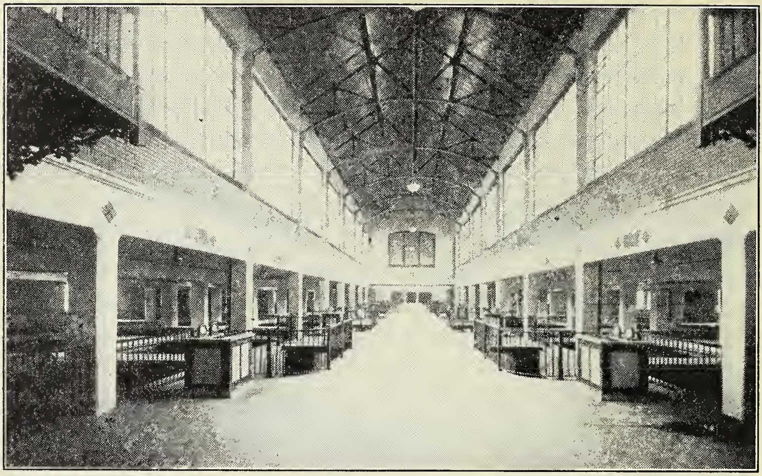


FIG. 48. Tell how each layer of a filter bed helps to purify water.

A filtration plant is made up of a number of *filter beds;* a large filtration plant may have as many as forty. A filter bed is a large concrete tank about 30 feet wide, 40 feet long, and 25 feet deep (Fig. 48). The bottom of the tank has an outlet to the water main (pipe). Beginning at the bottom of the tank are successive layers, each two to four feet deep, of broken stone, coarse gravel, fine gravel, and sand, in the order given. These layers, which together are a depth of 12 to 15 feet thick, form the filter.

After the filter bed has been completed, water from the settling basins flows onto the top of the filter to a depth of nine or



Courtesy Cleveland Water Works Dept.

FIG. 49. In this filtration plant there are ten filters on each side of the middle aisle. Notice the control cabinet for each filter. It regulates the flow of water through a filter.

ten feet. The weight of the water causes it to sink down gradually through the sand, gravel, and broken stone into the water main. This process is called *filtration.* Figure 49 shows an interior view of part of a city water filtration plant.

After a filter bed has been in use for a time, a jelly-like layer forms on the top of the filter. This layer consists of particles from the settling basin and green particles which are really tiny water plants. This layer is very necessary in the purification of water because it entraps and kills most of the germs. Sometimes, instead of this layer, the top layer of a filter bed consists of a jelly-like substance prepared from chemicals.

Filter beds in continuous use must be cleaned (washed), for the germs which collect in the top film in time extend gradually downward through the bed, so that water which passes through the filter is not sufficiently freed of germs. Such a filter is washed by forcing pure water up through it from the bottom. The wash water overflows into a drain and is carried away. In this way the impurities in the filter are washed out of it.

How chlorine helps in the purification of water. Water which has passed through a filter bed may still contain disease germs. To be safe for household purposes, water must be almost free from these germs. In order to kill all germs which may remain in the filtered water, chlorine is used. A very small amount of chlorine added to filtered water is sufficient to kill disease germs quickly, but it does not make the water harmful to those who use it.

How ammonia helps in the purification of water. In many cities water intended for household use contains much chemical wastes from industrial plants. These cannot be removed by the use of alum or by filtration. Although certain of these chemicals are harmless, nevertheless, when they combine with chlorine, they give the water a very bad taste and odor. Chemists have found that the addition of a small quantity of ammonia to filtered water before chlorine is added will keep the water odorless and pleasant to the taste. Consequently, ammonia has become very necessary in the purification of water for some cities.

How boiling helps in the purification of water. The harmful germs which water may contain can be killed by boiling the water. Boiling, however, drives out the air which water naturally contains and gives the water a "flat" taste. If it is necessary to boil water to purify it either at home or at camp, air may be mixed with the water by pouring it from one vessel to another several times.

The purification of water by distillation. Impure water may be purified by distillation (page 91). In addition to dissolved air, natural water contains other dissolved substances such as common salt, lime, compounds of iron and magnesium, and the like. These substances if in the right amounts give water a pleasant taste. Distilled water is pure water, as you will learn later. To make distilled water agreeable to the taste it should be treated in the same way as boiled water.

What is hard water? Rain water contains little, if any, dissolved substances. But as water comes in contact with rocks and soils, as you have learned, it dissolves compounds of calcium, and the like. If water contains so much of these substances that it does not form soapsuds readily, it is said to be "hard."

Experiment 29. To determine whether water is "hard" or "soft." Make a soap solution by adding soap shavings to 10 cc. of grain alcohol until no more soap will dissolve. With a medicine dropper add two drops of the soap solution to: (1) a test tube half full of distilled water; (2) a test tube half full of well water or city water; (3) a test tube half full of distilled water in which a pinch of calcium chloride has been dissolved.

Place your thumb over the open end of test tube 1 and shake it vigorously. What happens? Do the same with each of the others. What happens in test tube 2? In test tube 3? In which tube or tubes did a white scum form? In which did soapsuds form without a scum? Is water that forms a white scum when soap is added "hard" water or "soft" water? How did the calcium chloride affect the water?

Is the water you use at home hard or soft? If you do not know, test it to find out.

Experiment 30. To show how hard water can be made soft. Fill a test tube half full of well water or city water. Fill another test tube half full of distilled water and add a pinch of calcium chloride. Why was the calcium chloride added? Add a pinch of washing soda to each test tube and shake well. Now add two drops of soap solution to each and shake well. Does the water in each tube make soapsuds easily? Does a scum form in either tube? From this experiment tell one way in which hard water can be made soft.

How is boiler scale formed? "Hard" water containing bicarbonate of calcium and bicarbonate of magnesium may have its hardness greatly lessened by boiling. Most teakettles become coated on the inside with minerals deposited from water boiled in them. If "hard" water is used in a boiler, the mineral substances in solution are deposited on the inside of the boiler just as they are deposited on the inside of a teakettle. As this deposit, called "boiler scale," becomes thicker and thicker, it takes longer and longer (in other words, takes more and more fuel) to heat the water in the boiler. Give a reason why boiling hard water makes it less hard.

PROBLEM: HOW IS WATER BROUGHT INTO A HOME AND USED TO DISPOSE OF WASTES?

Bringing water into the house. To make running water available in homes, force or pressure is necessary. As pure water weighs 62.4 pounds per cubic foot, you can readily see that water in a reservoir exerts pressure on its bottom and sides. If a city reservoir is located on ground high enough, the pressure of the water in the reservoir will force water through pipes to homes in the city. If it is not possible to locate a reservoir on ground high enough to provide the pressure necessary to pipe water throughout a city, pumps are employed to raise the water into large standpipes for storage.

If you live in a city, the water you use probably comes from a reservoir through a pipe, usually called a water *main*, under the street. The size of the main depends upon the amount of water needed for all the houses it is intended to serve. A smaller pipe conducts the water from the main to your house. In the house the water is turned on and off by means of faucets. A faucet is a spout with a valve in it (Fig. 50). All faucets, pipes, and other connections of the water system should be free from leaks, and they should be strong enough to withstand the pressure of the water in the water system. If water pipes become clogged with dirt or rust, the water pressure has to overcome increased friction, thus reducing the flow of water. Water pressure must be sufficient to supply water to homes in the highest parts of a community and to the tops of the tallest buildings even though they also are in the highest parts of a city.

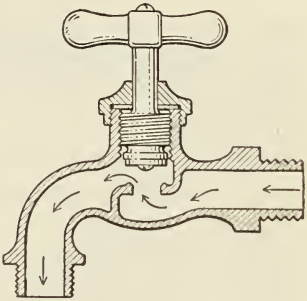


FIG. 50. How is water turned off by this faucet?

Water for smaller towns is sometimes pumped from deep wells into large elevated tanks or standpipes to provide a supply of water at the required pressure.

Experiment 31. To construct a model water supply system. Set up apparatus as shown in Figure 51. Use the force pump to fill the bottle which represents the reservoir. Open the stopcock at the reservoir to let water into the system. Then open stopcocks at different points to make sure that the system will supply water to all its parts. How is water pressure provided in this system? Name a town or city that has a water supply system based on the same principle.

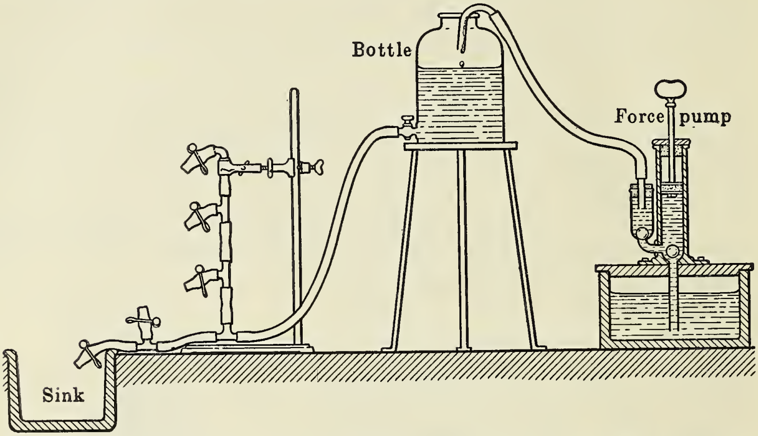


FIG. 51. A model of a water supply system. Tell what each piece of apparatus corresponds to in a real water supply system.

Water systems in the country. In many rural homes, an electric motor, gasoline engine, or a windmill is used to pump water into a tank elevated high enough to provide the pressure necessary to force water through pipes to all parts of the farm-buildings. Another way of forcing water to all parts of the farm is by means of a pressure tank into which water is pumped until the pressure of the compressed air above the water is sufficient to force the water through pipes. The principle of the compressed air chamber is the same as that of the compressed air chamber in a force pump. By the use of such systems, buildings in the country may be provided with an adequate supply of running water. In this respect a country home can be made the equal of a city home; the same kind of bathroom and kitchen equipment may be used.

Disposal of waste water and sewage. It is just as necessary to have all wastes conducted away from the home as it is to have a supply of pure water. All waste pipes from toilets and the like should be provided with "traps" to prevent disagreeable gases from entering the house from the waste pipes. There are different kinds of traps, but practically all have an arrangement whereby water is kept standing in the waste pipe to prevent the passage of disagreeable gases. A familiar type is the one sometimes called a "goose neck" trap, because the curve in the pipe resembles the curve of a goose's neck (Fig. 52).

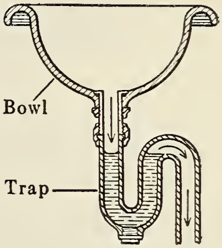


FIG. 52. How many traps are a part of the plumbing in your house?

We see that water is necessary to carry away human wastes (sewage) to places where it can be rendered harmless. The final disposal of all sewage is brought about by tiny plants (*bacteria*) that cause decay. These bacteria are aided by other bacteria that live in the soil and make use of waste material. In time bacteria will change sewage into harmless liquids and solids; it has been found that a stream of water into which sewage has been dumped will purify itself provided the helpful bacteria have sufficient time to do their work. Unless great care is exercised, however, water containing human wastes may find its way into wells and cisterns before the bacteria have completed their task of purification. For this reason it is necessary to provide places where the sewage may remain until the bacteria have finished their work.

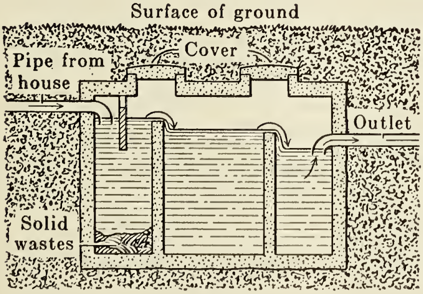


FIG. 53. A septic tank. Note carefully each part and make sure you know how it does its work.

Sewage disposal in the country. In the country one of the most effective ways of preventing dish water, wash water, and

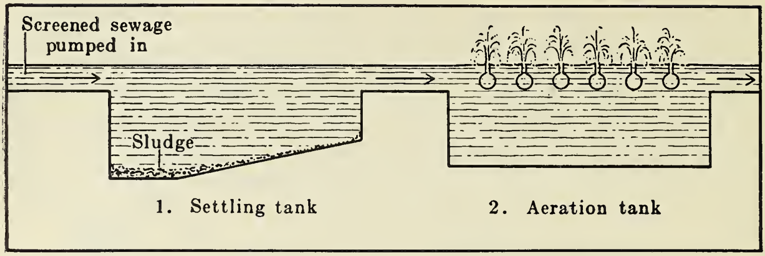


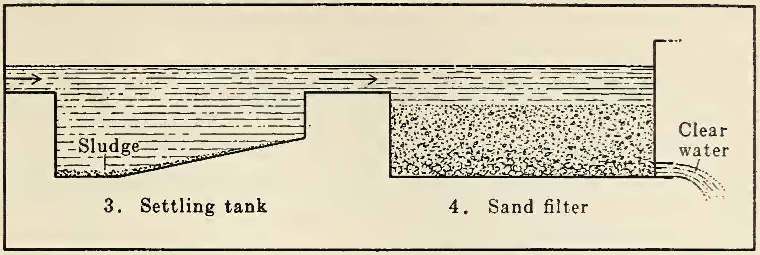
FIG. 54. Sewage is first screened to remove some of the solid material. It is then pumped into a settling tank from which the sludge is removed at

human wastes from seeping into a well and thus contaminating the water supply is by the use of a septic tank underground. A septic tank (Fig. 53) is built of brick or concrete and consists of two or more water-tight compartments connected with one another. Wastes from the house are carried by water from a water supply system through an underground drain to the septic tank. The liquid and solid wastes pass from the drain into the first compartment, where bacteria change some of the solids into gases and liquids. A few solids (sludge) remain and collect on the bottom. The liquid wastes overflow into the next tank; here bacteria continue to act on them until they are rendered harmless. Finally, the harmless liquid flows out of the last tank and is absorbed by the soil. The use of the septic tank has prevented many illnesses that result from contaminated water.

Sewage disposal in the city. The problem of disposing of wastes in cities is even more difficult than in the country. Some cities are so situated that they can drain their sewage into an ocean. Other cities drain their sewage into nearby lakes and rivers.

In consequence of this practice of dumping sewage into nearby bodies of water, many cities have been ravaged by terrible epidemics of cholera and typhoid fever and the like, caused by using sewage-laden water which had been only partially purified by helpful bacteria. Cincinnati, Cleveland, Chicago, and other cities suffered from typhoid fever epidemics before it was known how to purify water.

Many cities have constructed sewage disposal plants (Fig. 54) somewhat on the principle of the septic tank but on a much larger



intervals. The sewage then runs into an aeration tank, from there into a second settling tank, and finally may run through a sand filter.

and more complicated scale. The sewage is sprayed into the air to supply oxygen for aerobic bacteria. The tanks in which solids collect are cleaned at regular intervals and the sludge made into fertilizer. The remaining liquid is filtered and treated with chemicals. The end product is water which, in certain kinds of sewage disposal plants, is safe for drinking purposes.

How does your community dispose of its sewage? If you live in the country, does your home have a sewage disposal plant?

How is water measured? The amount of water used in a home, a factory, or the like, is measured by a water meter, usually in cubic feet. The meter is connected to the water supply pipe near the place where it enters the basement, so that all the water used flows through the meter. It has the shape of the upper half of a sphere with a turret-like top. The cover of a meter is made usually of bronze, to prevent rusting. If you have a water meter in your home, an examination of it will help you to understand its construction and how it is read.

Most small meters are of the disk type. The moving part in the measuring chamber is a hard rubber disk which rotates with a wobbly or nodding motion as water passes through the meter. This motion is something like the movement of a cart wheel lying on its hub while someone walks around on its rim. One rotation of the disk shows that a specified amount of water has passed through the meter.

The machinery attached to the upper part of the disk moves the hands on the dial register. The dial register can be seen by lifting a lid, part of the top of the meter. The dials usually measure one, ten, one hundred, one thousand, ten thousand, and one hundred thousand cubic feet of water.

Leaks in faucets cause considerable water to be wasted. This wasted water has flowed through the meter, incurring unnecessary expense. To measure the amount of water passing through the pipes because of leaks, observe the one-foot dial when no one in the house is drawing water. The one-foot dial moves if there is a leak of any consequence.

Readings on the water meter are usually taken quarterly, and for most small homes the number of cubic feet can be read on the ten-thousand cubic foot dial, if a water company or water department charges a certain sum for each thousand cubic feet. Some meters have what is called a "straight-reading register," something like the one indicating the number of miles traveled by an automobile, except, of course, that they measure cubic feet of water.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

alum
ammonia
bacteria
boiler scale
calcium compound
chlorine
cholera
disease germ
epidemic
faucet
filter bed
filtration plant
magnesium compound
mineral matter
organic matter
reservoir
purification
septic tank
sewage
stand pipe
trap
unfiltered
washing soda
water meter

Write the number of each item on your paper and after it the word that completes the statement.

1. Perhaps the most famous water system of ancient times was that of __________.

2. Muddy water can be made clear by treating it with __________.

3. Purifying water by allowing it to flow through sand, gravel, and broken stone is known as __________.

4. In order to kill disease germs ________ is frequently added to a water supply.

5. A modern means for securing water pressure in country homes is the air ________ tank.

6. Water which does not readily form soap suds is known as ________ water.

7. Water used in the home is measured by a ________.

Which item in each of the following lists does not belong with the others?

8. filter bed; broken stone; sand; calcium compounds; jelly-like film.

9. calcium compounds; hard water; washing soda; soap suds; chlorine.

10. septic tank; water meter; sludge; bacteria; human wastes.

Which of these statements are true? If any are false, re-state them in correct form.

11. Clear water is always safe to drink.

12. A small quantity of ammonia is sometimes put into a city water supply to kill bacteria.

13. Soft water does not contain mineral matter.

14. People living in the country never have water pressure systems.

15. Water from a sewage disposal plant is usually harmful.

CHAPTER VII

OF WHAT IS WATER COMPOSED AND WHAT ARE SOME OF ITS PROPERTIES?

Do you know:

That electricity will break water down into two gases? What liquid forms as hydrogen burns? What the lightest known gas is? What solutions you use almost daily? What happens to water when it evaporates? Why distilled water is used in the battery of your car?

Why sprinkling a sidewalk on a hot summer day has a cooling effect? Why wet clothes hung on a line dry faster if there is a breeze? Why water boils on Pike's Peak at a lower temperature than at sea level? How ice is manufactured? What makes the interior of an electric refrigerator cold?

PROBLEM: OF WHAT IS WATER COMPOSED?

In former times water was thought of as an element. People laughed at the idea that water could be broken down (decomposed) into two gases. The following experiment will show you how water is decomposed by an electric current. The decomposition of water by an electric current is called the *electrolysis* of water.

Experiment 32. To show the electrolysis of water. The apparatus in Figure 55 should be used if available; if not, set up the one shown in Figure 56. If the latter apparatus is to be used, fill the two test tubes, which are of equal size, with water and insert them in a small basin of water so that their mouths are below the surface of the water.

A battery composed of four dry cells will be needed for the experiment. Attach a wire to each pole of the battery; place the free end of one of the wires in one of the test tubes and the free end of the other wire in the other test tube. If a small piece of platinum foil is attached to each of the free ends of the wires, the gases will be given off more rapidly. A few drops of sulfuric acid should be added to the water.

If the apparatus in Figure 55 is to be used connect it in an electric circuit and turn on the current. Observe what is happening inside the test tubes. What happens? In which tube does gas collect the faster? After fifteen minutes turn off the current. Have the gases collected in equal volumes? How do the two volumes compare?

Disconnect the test tube which has the smaller volume of gas in it. Place your thumb over the mouth of this tube and invert it. Thrust a glowing splint into the gas in the tube. What happens? What gas that you have previously studied behaves in this way? What gas do you believe this one to be?

In the same way invert the other test tube.

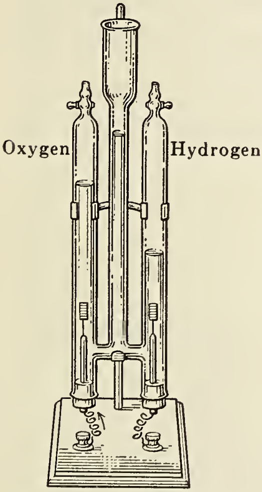


Fig. 55. This apparatus is used to break down water into oxygen and hydrogen.

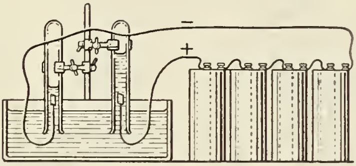


Fig. 56. A simple apparatus for determining the composition of pure water.

Bring a flame to the mouth of the tube. What happens? This gas is hydrogen. This experiment shows that water may be decomposed into what two gases?

From many similar experiments and from other experiments scientists have learned that water is composed of two gases, hydrogen and oxygen; and that when these gases unite to form water, two parts by volume of hydrogen always unite with one part by volume of oxygen.

If 40 cubic centimeters of oxygen are obtained by decomposing water, how many cubic centimeters of hydrogen are obtained at the same time?

Hydrogen, its properties and uses. In Experiment 32 you learned that hydrogen will burn. Now we will prepare hydrogen and learn more about its properties.

Experiment 33. To prepare hydrogen and to study its properties. (Teacher's demonstration.) Put a small handful of granulated zinc into a wide-mouthed bottle. Fit the bottle with a two-hole rubber stopper. Through one hole of the stopper pass a thistle tube long enough for the lower end to reach to within one-half inch of the bottom of the bottle. Through the other hole insert a glass tube and connect it with a delivery tube leading to a pneumatic trough (Fig. 57).

Pour hydrochloric acid diluted with water through the thistle tube until the acid rises slightly above the lower end of the tube. Notice what occurs inside the bottle. Does the bottle feel warm or cold? The gas which is being formed is hydrogen. The gas that comes from the delivery tube at the beginning of the experiment is hydrogen mixed with air. It should not be used because it will explode violently.

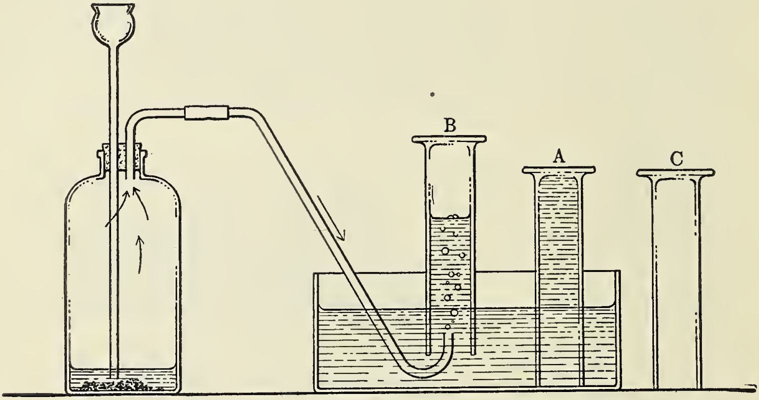


Fig. 57. Collecting hydrogen. *C* is filled with hydrogen; *A* is filled with water; *B* is filling with hydrogen and displacing water.

To determine whether the gas is pure hydrogen or nearly so, collect a small quantity by holding an inverted test tube over the end of the delivery tube. After waiting a few seconds for the test tube to fill with gas, carry it mouth downward and hold it over a flame a few feet away. If the hydrogen in the test tube does not explode but burns instead with a flame that rises slowly up the tube, the gas is now pure enough to be collected for use in the experiment.

Collect two or three bottles of hydrogen and stand them mouth downward on pieces of cardboard on a table. Do not place them near a flame. Why? Note whether the gas has a color and an odor. If the gas remains in the inverted bottles for some time, does this show it to be lighter or heavier than air? Explain.

Carry a bottle of hydrogen mouth downward and hold it over a lighted candle (Fig. 58). What happens? If there is a mild explosion when the bottle is held over the candle, it indicates that the gas is not quite pure. Notice, however, what is going on inside the bottle. Does hydrogen burn? Lower the bottle slowly over the lighted candle, and note that the candle flame has been extinguished. Slowly raise the bottle again and notice that the candle has relighted. Explain how this happens. Does hydrogen support combustion? Give reasons for your answer.

Make a list of the properties of hydrogen shown by this experiment.

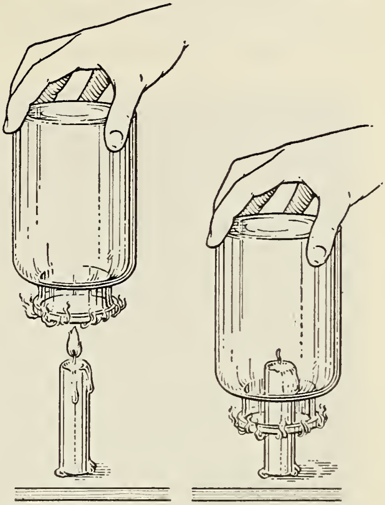


FIG. 58. Does hydrogen support combustion? Explain.

Hydrogen resembles oxygen in that it is colorless, odorless, and tasteless. It is the lightest of all known elements. One liter (a little more than one quart) of hydrogen weighs about .003 ounce. It is not only one of the elements of which water is composed, but also one of the elements of which all living matter is composed. Therefore it is a part of nearly everything we use for food. United with carbon, it is found in petroleum and natural gas. Coal, though largely carbon, contains hydrogen.

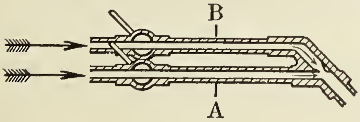
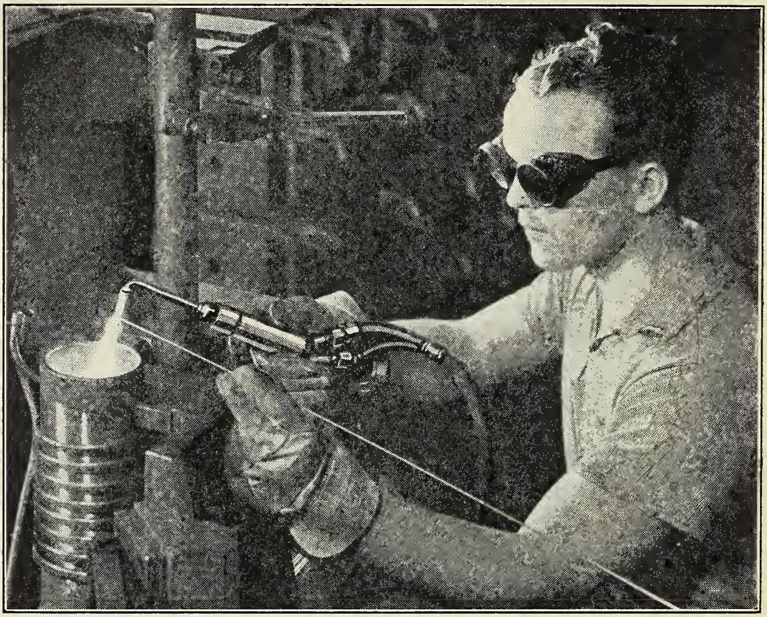


FIG. 59. Oxyhydrogen blowtorch. Oxygen that passes through pipe *A* mixes with hydrogen that passes through pipe *B*. These gases stored in tanks, are forced through the small pipes by pressure.

Hydrogen is used in a great variety of industrial processes. For instance, in the preparation of a solid fat from cottonseed oil, hydrogen unites with the liquid oil to form a solid fat; this fat is used as a substitute for lard and also to supply the fat in some kinds of oleomargarine.

Hydrogen mixed with oxygen is burned in an oxyhydrogen blowtorch (Fig. 59). This blowtorch is used by jewelers and others to melt and weld certain metals such as platinum, which is damaged by gases ordinarily used to weld or melt metals with high melting points. Workers in laboratories and plumbers use a blast lamp. This lamp burns coal gas which contains about 50% hydrogen. It also burns natural gas which is mostly methane. This gas consists of carbon united with hydrogen. The gas is mixed with air and burns much as hydrogen burns in an oxyhydrogen blowtorch. Acetylene, which is used in the oxyacetylene blowtorch employed in welding (Fig. 60) and cutting metal also consists of carbon united with hydrogen. As stated before, hydrogen is used to inflate balloons and airships if helium is not available.



Courtesy Linde Air Products

FIG. 60. Welding parts of a refrigerator with an oxyacetylene blowtorch. The flame melts the parts and also melts the end of the welding rod which is held in the man's left hand. The fused (melted) metal runs together. When it cools the parts are welded.

PROBLEM: HOW IS WATER USED TO MAKE SOLUTIONS?

Water for everyday purposes is a solution. When we say that water is a compound of hydrogen and oxygen, we mean chemically pure water, that is, water that does not contain any other substance. It is very unusual, however, to secure from any natural source water that is chemically pure. Very probably even a drop of rain is formed around a tiny grain of dust in the air. Consequently, the water used for everyday purposes, is not the compound of hydrogen and oxygen alone but that compound and other substances. Water that is not chemically pure is a solution.

Experiment 34. To make a solution of common salt and water. Place a small quantity of salt in a test tube about half full of water. What happens to the salt? Taste the water. Does the taste prove that the salt dissolved? Why?

A mixture composed of a solid, a liquid, or a gas dissolved in a liquid is called a *solution.* The liquid in which another substance is dissolved is called the *solvent.* The substance dissolved is called the *solute.* In the salt solution in Experiment 34, which is the solvent and which the solute?

A *tincture* is a solution in which alcohol is the solvent. For example, tincture of iodine, frequently applied to fresh wounds, is an alcohol solution. What is the solute in tincture of iodine? The solvent?

If a substance dissolves in a liquid that substance is said to be *soluble* in that liquid. If we continue to add salt little by little to the water in the test tube (Experiment 34), we will find that the salt dissolves more and more slowly. Finally the salt falls to the bottom of the test tube as fast as added instead of dissolving. When a liquid (solvent) will no longer dissolve any more of a substance (solute), the solution is said to be *saturated.*

When a substance will not dissolve in a particular solvent, it is said to be *insoluble* in that solvent. If a small amount of a substance which is insoluble in water, such as starch, lime, flour, or clay, is put into water and the two are shaken vigorously, small bits of the substance are suspended in the water, causing the mixture to be cloudy. Such a mixture is called a *suspension.*

Properties and uses of solutions. The color of a solution depends on the solute; e.g., a solution of copper sulphate is blue; of potassium permanganate, purple. Regardless of the length of time a solution is left standing, provided evaporation is prevented and the temperature does not change, the solute neither settles to the bottom nor comes to the top. In general, solutions in which water is the solvent boil at higher temperatures and freeze at lower temperatures than water itself. The boiling point of pure water is 212° F. and the freezing point 32° F. A saturated solution of water and common salt boils at about 226° F., and freezes at about 0° F. How much is the boiling point raised and the freezing point lowered?

Solutions are used very commonly in daily life. Many different solutions are used in manufacturing and in agriculture. Certain medicines are in the form of solutions. Food taken by human beings is either in the form of a solution or is reduced to a solution by the processes of digestion before it can be absorbed into the body. Food materials taken by plants from the soil are in the form of solutions.

PROBLEM: HOW CAN WATER BE CHANGED INTO A GAS AND BACK AGAIN INTO WATER?

Experiment 35. To show the vaporization and condensation of water. Arrange apparatus as shown in Figure 61. Fill flask *A* half full of water. Fill jar *B* with cold water. Heat flask *A* with a Bunsen burner. When the water in *A* boils, what is it changing into? Where does this steam (water vapor) go? What is it changed into in the test tube? What is the purpose of the cold water in *B*?

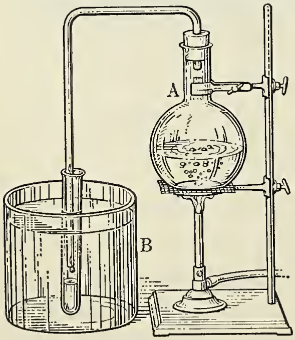


FIG. 61. Apparatus for vaporization and condensation of water.

The change of water from a liquid into a gaseous form is called *vaporization;* where did vaporization take place in this experiment? The change from a gaseous form into a liquid is called *condensation;* where did condensation take place in this experiment? If a liquid changes into a gas (vaporizes) and then the gas is changed back into a liquid (condenses), the two-fold change is called *distillation.*

Experiment 36. To show distillation, using a Liebig condenser. Procure a Liebig condenser, and set it up with other apparatus as shown in Figure 62. Notice the construction of the condenser and explain how it operates. Fill flask *A* half full of muddy or colored water. Boil the water in *A*. What happens in the other parts of the apparatus? What is the color, odor, and taste of the water in *D*? Should the cold water pass into the condenser at *B* or *C*?

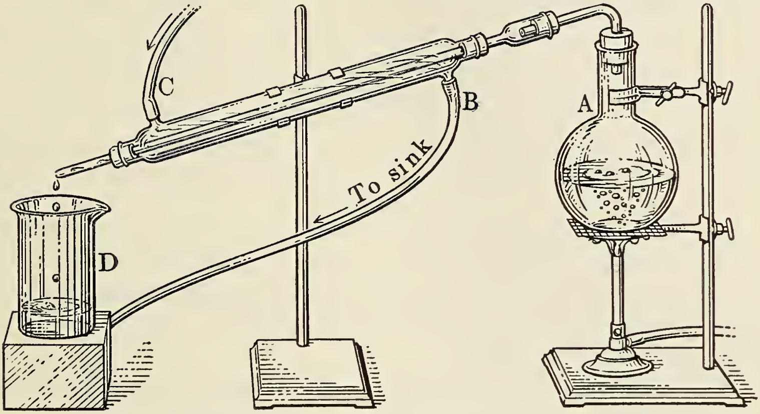


FIG. 62. Use this apparatus to explain the process of distillation.

Collect about half a beaker of distilled water in *D*. Evaporate a small part of it to dryness. What was left? Evaporate a small portion of tap water or well water to dryness. What was left? Does this experiment show that distilled water is chemically pure water? Why?

Even snow and ice vaporize, that is, evaporate. A light snowfall may disappear by evaporation, even though the temperature remains below the freezing point of water. Sometimes when the temperature is below freezing, wet clothing hung out of doors will freeze and remain frozen. Eventually the ice in it evaporates and the clothing becomes dry.

How does the area exposed to air affect the rate of evaporation? If we wish to evaporate a pint of water, we can evaporate it more quickly if we put the water into a large, shallow pan rather than into a deep cup. You may have observed that water will remain in an open test tube for days before it entirely evaporates. The same volume of water in a large pan or spilled on the floor evaporates in a few minutes. Evaporation takes place only from the surface of a liquid; therefore, the greater the area exposed, the faster the rate of evaporation.

How does temperature affect the rate of evaporation? The rate at which a liquid evaporates depends also upon its temperature. The higher the temperature of a liquid the faster is the rate of evaporation as the following experiment will show.

Experiment 37. To show that a rise in temperature increases the rate of evaporation. Fill each of two evaporating dishes half full of water. Put one on a shelf in the room and place the other over a low flame. Observe each dish every five minutes. From which dish is water evaporated the faster? How does a rise in the temperature of water affect its rate of evaporation? How do you think cooling water affects its rate of evaporation? If we are in a hurry to dry a piece of clothing, why do we place it near a warm radiator?

How does atmospheric pressure affect the rate of evaporation? You have learned that the normal pressure of the atmosphere on the surface of the earth at sea level is 14.7 pounds per square inch. You know, too, that a barometer "rises" and "falls," because the atmospheric pressure at a given place is greater at certain times than at others. In other words, atmospheric pressure in any locality changes. It changes also with elevation above sea level. What did Pascal learn about atmospheric pressure when a barometer was carried up the mountain side? These changes in atmospheric pressure affect the rate of evaporation of a liquid. At the top of Pike's Peak water boils (rapid evaporation) at 187° F., whereas at sea level it boils at 212° F. Of course the lower boiling point is due to the decreased atmospheric pressure.

The air pressure above water in a pan with an air-tight cover may be lowered by creating a partial vacuum in the air space above the water. Due to the decreased pressure the rate of evaporation of the liquid is increased. On the other hand, evaporation in a pressure cooker is greatly retarded because there is an increased pressure in the space above the liquid. We see, then, that as the pressure of the atmosphere changes the rate of evaporation of water changes. How?

How does a current of air over water affect the rate of evaporation? The following simple experiment will show the effect of a current of air passing over water.

Experiment 38. To show that a current of air over water increases the rate of evaporation. Wet two pieces of cheesecloth of the same size. Place one piece under a bell jar where it is not exposed to a current of air. Place the other in an open window where there is a current of air. From time to time observe the two pieces of cloth. From which is water evaporating the faster? Explain. Would you expect clothes to dry more rapidly if the wind were blowing?

How does the amount of water vapor already in the air affect the rate of evaporation? The amount of water vapor which the air contains at sea level at any time varies with the temperature. If the temperature rises, the capacity of the air for holding water vapor is increased. If the temperature lowers, the capacity of the air for holding water vapor is decreased. The following table gives the greatest weight of water vapor that one cubic meter of air at sea level can hold at four different temperatures.

Temperature	0° C.	10° C.	20° C.	30° C.
Weight of water vapor	4.8 g.	9.9 g.	17.1 g.	30 g.

You can see from the table that, if the temperature is 20° C., a cubic meter of air can hold 17.1 grams of water. If this volume of air over water already contains very nearly this weight of water vapor, and if the temperature does not change, obviously one cubic meter of air is able to hold but little more water vapor and the rate of evaporation is decreased. On the other hand, if one cubic meter of air at 20° C. contains only two or three grams of water vapor, it can hold much more water if the temperature does not change and the rate of evaporation is increased. The greater the amount of water vapor already in the air, the lower the rate of evaporation if the temperature is unchanged.

We can now understand why a current of air affects the rate of evaporation. If the air is still over an open dish of water, it soon will contain the greatest possible weight of water vapor. If a current of air changes the air over the dish, the rate of evaporation of the water is increased.

Upon what does the rate of evaporation of water depend? As you have seen, the rate at which water evaporates depends upon: (1) the area exposed to the air, (2) the temperature, (3) the pressure of the atmosphere, (4) the amount of water vapor already in the air, and (5) the movement of air over the water.

Experiment 39. To show that evaporation is a cooling process. (a) Let two pupils stand before the class, holding both hands with palms upward. Pour a little water on one hand of one pupil and a few drops of alcohol on his other hand. Pour a few drops of alcohol on one hand of the other pupil and a like amount of ether on his other hand. After about five seconds, ask each pupil if both hands feel the same. What have you learned about the rate of evaporation of water, alcohol, and ether?

(b) Fasten absorbent cotton around the bulb of a thermometer. Record the temperature indicated by the thermometer. Moisten the cotton with ether or alcohol and, after waving the thermometer to hasten the rate of evaporation, record another reading of the thermometer. How do the two readings compare? Does evaporation lower the temperature? Does the result of this experiment agree with the result of (a)?

The preceding experiment shows that evaporation is a cooling process. You have learned that as a liquid evaporates, it changes to a gas. In every such change heat is necessary. The heat required for the process of evaporation is taken from nearby objects; as a result the temperature of these objects falls. If we pour water on our arms, evaporation begins at once; some of the heat used to evaporate the water is drawn from our arms; therefore our arms feel cooler.

How is the cooling effect of evaporation used in the manufacture of ice? The cooling effect of evaporation is made use of in the manufacture of ice. Different liquids do not evaporate at the same rate; alcohol evaporates more quickly than water, and ether still more quickly than alcohol. Liquid ammonia also evaporates rapidly; in fact, at ordinary temperatures it is always a gas unless it is subjected to a pressure greater than normal atmospheric pressure. At 80° F. a pressure of 155 pounds per square inch will reduce ammonia gas to a liquid. Due to the fact that ammonia gas can be changed to a liquid by pressure at ordinary temperatures, this gas is used in the manufacture of ice. Figure 63 is a diagram of the apparatus used in the manufacture of ice in a modern ice plant.

In explaining the process of manufacturing ice, we will begin with the pump and follow the arrows until the whole process is explained. The pump serves two purposes: (1) it reduces the pressure in the ammonia pipes in the brine tank *C*, and (2) it forces the ammonia gas into the condensing pipes *B*, keeping the pressure in them at about 155 pounds per square inch. In compressing a gas, heat is given off by the gas. This heat is known as the heat of compression. The heat of compression developed in the compressed gas by the pump is taken away by the cold water that passes over the condensing pipes *B*. The temperature of the ammonia in pipes *B* is kept at about 80° F., and as the ammonia is subjected to a pressure of 155 pounds per square inch, the gas changes into a liquid.

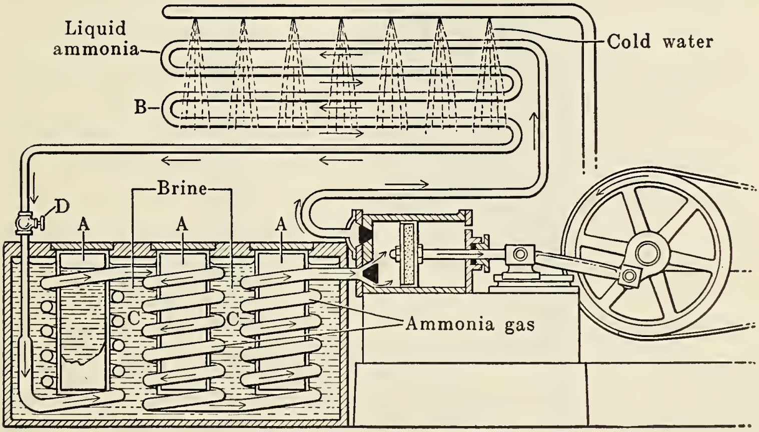


Fig. 63. Use this diagram of the essential parts of an ice plant to explain how artificial ice is made.

This liquid ammonia passes through the pipes to the expansion valve *D*, which is a regulating valve that permits the liquid ammonia to pass through just rapidly enough to prevent the pressure in the pipes in the brine tank *C* from rising much above thirty pounds to the square inch. As the liquid ammonia is set free by the expansion valve into a space of greatly reduced pressure, it evaporates very rapidly. The heat necessary for this evaporation is drawn from the brine in tank *C*. Since the brine is a salt solution, it may be cooled several degrees below the freezing point of water without itself freezing. This freezing mixture, the brine, which circulates around the containers *A* freezes the fresh water which they contain. The ammonia which, after passing through the expansion valve *D*, has become a gas, is used over again, thus making the process continuous.

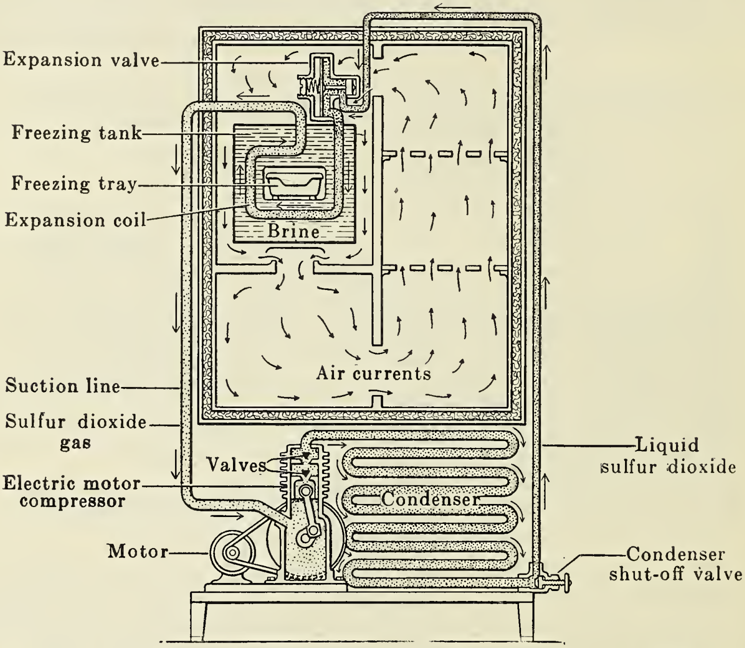


FIG. 64. Follow on the diagram of this refrigerator the various steps in the process of refrigeration and explain each as you reach it.

Certain cold storage plants utilize the same kind of apparatus except that a pump is used to force the cooled brine through pipes into the rooms used for cold storage or into other places where low temperatures are desired. Market stands are often equipped with these pipes, which, when in use, are covered with frost. In other cold storage plants, ammonia is allowed to expand in pipes placed along the ceiling or sides of a room, thus cooling the room.

Many advantages are enjoyed in modern life because of ice plants and refrigeration plants. In most parts of the world ice is necessary to keep food from spoiling; to obtain sufficient natural ice for all our needs is practically impossible. We must make artificial ice.

By means of refrigerator cars perishable food products can be carried for long distances without spoiling; fruits and vegetables can be shipped to all parts of our country with but little loss from decay. It is no longer necessary for us to wait for fruit to ripen and vegetables to grow in our own vicinity.

Air conditioning. Air-conditioning apparatus as now installed (1) keeps air at a comfortable temperature; (2) keeps air circulating; (3) filters the air, thereby removing dust and bacteria; and (4) controls the amount of water vapor in the air.

Air is cooled by passing it over coils of pipes that are cooled by cold running water or by an expanding gas (refrigerant) within them. Air is warmed by means of furnaces or stoves. It is circulated by fans and is filtered by passing it through filters. Water vapor is removed by passing air over cold pipes or by passing it through certain chemicals. Water vapor is increased by passing air over a fine spray of water or over water in heated evaporating pans.

Discomfort in warm weather is increased by too much water vapor in the air. During hot weather in most regions, air usually contains too much water vapor. Air conditioning removes some of it. During cold weather in many regions, there is too little water vapor in the air for the best health and comfort in heated buildings. Consequently, water vapor is added.

In air-conditioned buildings, air is usually brought in from the outside by means of fans. Doors and windows should be kept closed. This not only reduces noise from the outside, but also keeps out dust and dirt. Air conditioning is another step forward in safeguarding health and in increasing comfort.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

condensation
condenser
distillation
electrolysis
expansion valve
explode
hydrogen
insoluble
liquid ammonia
oxyacetylene
oxyhydrogen
platinum
refrigeration
soluble
solute
solution
solvent
tincture
suspension
saturated
vaporization

Write the number of each item on your paper and after it the word that completes the statement.

1. The decomposition of water by electricity is known as ________.

2. When hydrogen burns ________ is formed.

3. In a solution of salt and water the salt is known as the ________, and the water is known as the ________.

4. A solution that has alcohol for its solvent is known as a ________.

5. The process of changing a liquid into a gas and the gas then back into a liquid is known as ________.

6. Other conditions remaining the same, an increase in atmospheric pressure ________ the rate of evaporation.

7. Minerals in solution can be removed by ________.

Which word in each of the following lists does not belong with the others?

8. solution; filtration; saturation; solubility; solvent.

9. helium; hydrogen; oxygen; water; electrolysis.

10. heat of compression; suspension; ammonia; brine; expansion valve.

Which of these statements are true? If any are false, re-state them in correct form.

11. The color of a solution depends upon its solvent.

12. The amount of water vapor that air can contain varies with the temperature.

13. In the manufacture of ice, cooling is due to the expansion of a gas.

14. Other conditions remaining the same, the rate of evaporation increases as the amount of water vapor in the air increases.

CHAPTER VIII

HOW DOES MAN MAKE USE OF WATER PRESSURE IN INDUSTRY AND TRANSPORTATION?

Do you know:

Why a dam is made stronger at the bottom than at the top? Why a submarine seldom goes more than seventy feet below the surface of the water? Why the diving suit of a deep sea diver must be made to withstand great pressure? Why a fish accustomed to living deep in the sea would burst if it were brought near the surface? How water pressure is used to bale cotton? How a barber chair is raised?

Who Archimedes was? Why a steel ship floats on water? How a submarine sinks below the surface of the water and rises again? Why you can lift a person off his feet in the water much easier than you can on land? Whether an iron ring floats on mercury? Why oil will float on water?

Problem: How Is Water Pressure Measured?

Just as the great ocean of air exerts pressure upon the surface of the earth and the sea, so the great oceans of water exert pressure upon the ocean beds. What is the pressure of the atmosphere on each square inch of surface at sea level? How does the pressure of the atmosphere vary with distance above sea level? You know that the pressure of the atmosphere at sea level is about the same in every part of the earth because the depth of atmosphere at sea level is the same everywhere. Suppose you ascended to the top of a mountain three miles high; the depth of the atmosphere there and its pressure would be less than they are at sea level.

Now let us see whether the water pressure at a given point below the surface bears any relation to the distance of that point below the surface. If a submarine goes twenty feet under water, is it subjected to greater pressure than at a depth of ten feet?

Experiment 40. To show that the pressure of water changes with the depth. Stretch a rubber diaphragm over the mouth of a thistle tube and attach the tube to a pressure gauge (Fig. 65). Press diaphragm *A* with your finger. What happens to the liquid in tube *B*? Does an increase in pressure on *A* cause the liquid in *B* to rise?

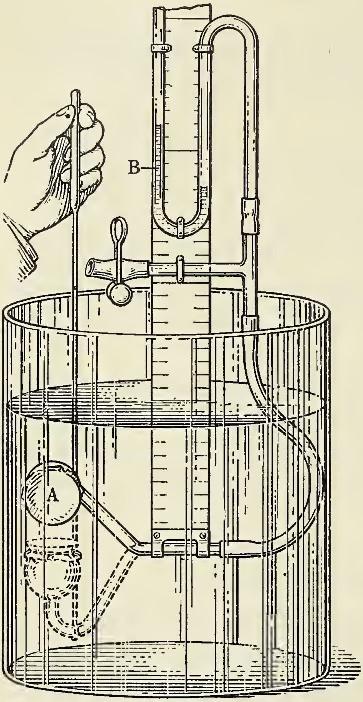


Fig. 65. The pressure of a liquid increases with its depth. Why?

Insert the apparatus into a deep jar filled with water. As the diaphragm is lowered in the water, what happens to the liquid in *B*? What is the effect of doubling the depth? Trebling the depth?

Test the pressure at the same depth with the diaphragm in a number of different positions. What do you find? Is there any difference in the pressure at the same depth if the diaphragm is turned downward? Upward? To the right? To the left? Do you conclude from your answers to these questions that at a given depth in a liquid the pressure is the same in every direction?

How does the pressure of water vary? Does Experiment 40 show that the pressure of water increases as the depth increases? Would the pressure on the sides of the container near the surface of the water be greater or less than near the bottom? Suggest a reason why a dam is always made stronger at the bottom than at the top. This increase of pressure with depth is true not only for water but for all other liquids and also gases. Do you understand now why the air pressure decreased as Pascal carried a barometer up a high tower?

This experiment shows us also that the pressure of water at a given depth is exerted equally in all directions; i.e., whether upward or downward, to the right or to the left. Do you think this is true for all other liquids? Why?

A given volume of gasoline weighs less than an equal volume of water. Would you expect the pressure of gasoline one foot below its surface to be greater or less than the pressure of water one foot below its surface? How does the pressure of gasoline on the bottom of a container compare with that of an equal depth of water?

How can you find the pressure on the bottom of a container? If a container is filled with water to a depth of 10 feet, then a column of water 10 feet high is pressing down on each square foot of the bottom of the container. In other words, the weight of 10 cubic feet of water is pressing down on each square foot. But one cubic foot of water weighs 62.4 pounds. Hence 10 × 62.4, or 624 pounds, is the pressure on each square foot of the bottom of the container.

In general, to find the total pressure of a liquid on the bottom of a container find (1) the area of the bottom, (2) the depth of the liquid, and (3) the weight of one cubic unit of the liquid. The product of these numbers is the pressure on the bottom of the container. If the depth is found in feet, in what unit should you find the area? What unit volume of the liquid must you know the weight of? If you knew the weight of one cubic centimeter of a liquid, in what units would you find the depth and the area?

To find the pressure of water against one side of a container. To find this pressure we must know the area pressed against by water, the weigh of one cubic foot of water and the *average depth* of the water pressing against the side of the container; but what is meant by average depth?

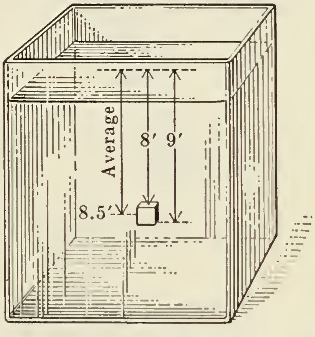


FIG. 66. Tell how to find the average depth of water in this container.

To find the meaning of average depth we will consider the water pressure against one side of the cube, one foot on a side, shown in Figure 66. The depth of the water at the top of the cube is 8 feet, and at the bottom the depth is 9 feet. Therefore, the average depth of the water pressing against this square foot of surface is

8.5 feet. Consequently, the pressure against one side of the cube is: 1 × 8.5 × 62.4, or 530.4 lb.

The depth of the water pressing against one side of the container (Fig. 66) at the surface is zero, at the bottom it is 10 feet, and the average depth is 5 feet. The pressure against the side of the container is the product of the three numbers that represent the area of the surface pressed against by the water, its average depth, and the weight of one cubic foot of water.

The depth of the water in the container (Fig. 66) is 10 feet. The width of the side of the container is 6 feet; what is the pressure against one side?

Experiment 40 taught us that at a given depth the pressure of a liquid is the same in all directions. Consequently the pressure of a liquid is not dependent upon the shape of a container, but only upon (1) the area of the surface pressed upon, (2) the depth of the liquid, and (3) the weight per cubic foot of the liquid.

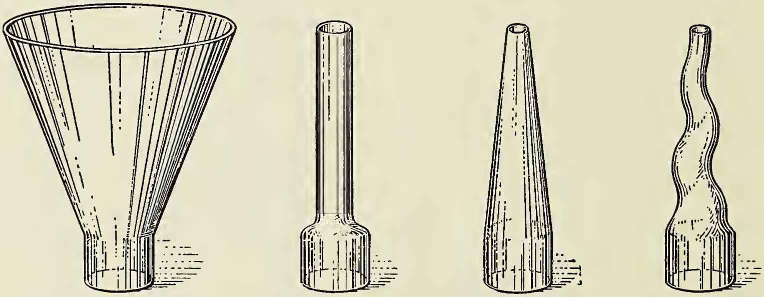


FIG. 67. These irregular containers have equal bases. If filled with water to the same depth would the pressure on their bases be equal?

PROBLEM: HOW IS A FORCE EXERTED UPON AN ENCLOSED LIQUID TRANSMITTED BY THE LIQUID?

You have already learned that the pressure of a liquid upon the sides and bottom of an open container depends upon (1) the area pressed upon, (2) the depth of the liquid, and (3) its weight per cubic unit. Now we shall discover what happens when a force is applied to a liquid that fills a closed container.

Experiment 41. To show how pressure is transmitted by a liquid in a closed container. Procure a pressure syringe like the one shown in Figure 68. Fill the syringe with water and, by pushing on plunger *A*, force water out. Push the plunger again. Did the water spurt from each opening with equal force? Is the water pressure the same at each opening?

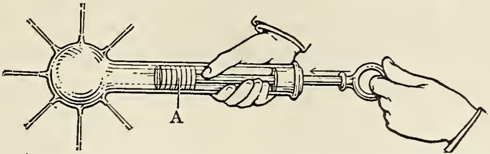


FIG. 68. A pressure syringe. What does the drawing show?

This fact was discovered by the French scientist, Pascal, and was stated by him in the form of a scientific law, as follows: Pressure applied to a liquid in a closed container is transmitted equally and undiminished in all directions.

The hydraulic press. The principle stated in Pascal's law has been applied extensively in modern industry, especially in the operation of the *hydraulic press.* Figure 69 shows how pressure

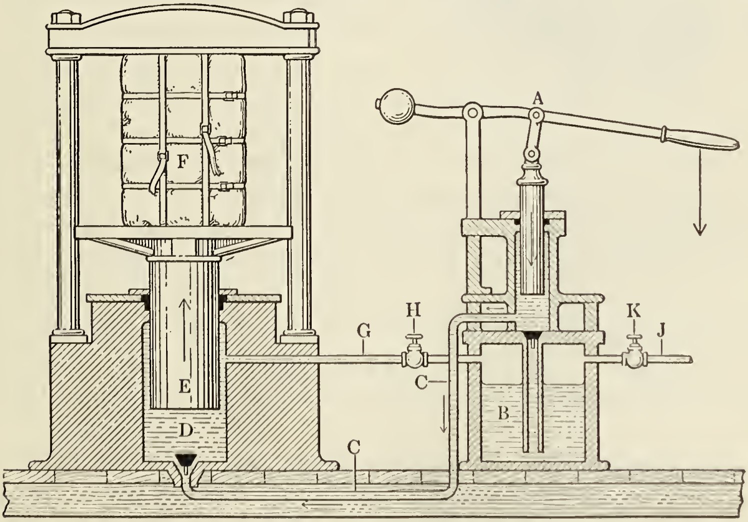
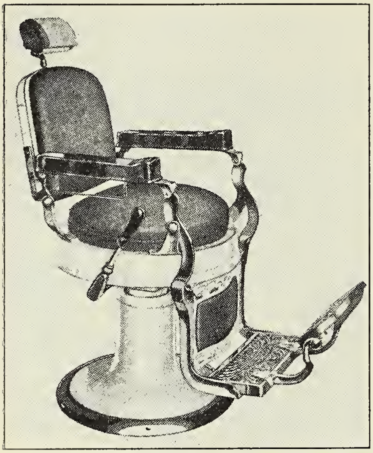


FIG. 69. An hydraulic press. On the downward stroke of pump *A*, the liquid that is forced through pipe *C* into compartment *D* exerts a pressure on piston *E*. To release piston *E*, the valve at *H* is opened, allowing the liquid to flow through pipe *G* back to compartment *B*. Liquid may be added in chamber *B* through pipe *J* and valve *K*.

is transmitted by a liquid in the hydraulic press. Notice that when a pressure is applied to the small piston, the liquid is forced through tube *C* into chamber *D*. The pressure of the liquid pushes the large piston, which exerts pressure on the bale.

You know by Pascal's law that the pressure per square inch or per square foot must be the same for each piston. Suppose, for example, the cross sectional areas of the two pistons to be 2 square feet and 12 square feet, respectively. Then a pressure of 10 pounds applied to the small piston would equal a pressure of 10 ÷ 2 or 5 pounds per square foot. There must be, then, the same pressure on each of the 12 square feet of the large piston, or a total pressure of 60 pounds.



Courtesy Eugene Berninghaus Company

FIG. 70. A barber's chair, which is raised by hydraulic pressure.

Uses of the hydraulic press. The hydraulic press is used to bale hay, paper, cotton, and the like; to extract oil from seeds; to punch holes in metal and to test the strength of metal; to press steel and to roll it into tubes; and to do many other things that require great pressure. The principle of the hydraulic press is also employed in the handling of great weights; for example, in rubber tire factories many tons of tires inclosed in their iron molds are lifted by a hydraulic press after they have passed through the heating process. You have probably seen barber chairs (Fig. 70) and dentist chairs which employ the principle of the hydraulic press. Where is the small piston in such a chair? The large piston?

Hydraulic brakes. Hydraulic brakes used on certain kinds of automobiles represent another application of Pascal's law. When the motorist presses his foot on the braking pedal of an automobile equipped with hydraulic brakes a pressure is communicated to a hydraulic system connected with the brake on each wheel. Oil is used in these hydraulic systems instead of water. Why?

PROBLEM: WHAT CAUSES CERTAIN BODIES TO FLOAT?

Why do certain bodies float? Archimedes, a great scientist and mathematician who lived in Syracuse, Sicily (287–212 B.C.), discovered that (1) a floating body displaces its own weight of the liquid in which it is floating, and that (2) a body immersed in a liquid is supported (buoyed up) by a force equal to the weight of the liquid displaced.

The story is told that Hiero, the ruler of Syracuse, suspecting that a crown made for him was not pure gold, ordered Archimedes to discover whether or not the goldsmith had defrauded him. The difficulty confronting Archimedes was how to make this discovery without destroying the crown. While in his bath one day Archimedes happened to notice that his body was buoyed up by the water, and the idea occurred to him that any other body immersed in water would be buoyed up by a force equal to the weight of the water that body displaced. By the use of his discovery, Archimedes solved his problem. Explain.

The force that buoys up a body immersed in a liquid is called a *buoyant* force.

Experiment 42. To show why a cork floats on water. Hold a cork at the bottom of a jar containing water; then release it. What happens? This action is due to the buoyant force of water. This buoyant force exerted on the cork is equal to the weight of the water it displaces. When a cork is held under water it displaces a weight of water greater than its own weight, and consequently when released it is forced upward to the surface of the water where it floats.

Experiment 43. To show that a cup made of material heavier than water will float. Float a tin cup on water. Dry the cup and weigh it. According to the law of floating bodies, what weight of water was displaced by the floating cup? Also, how great a buoyant force was acting to cause the cup to float?

Float the cup on water again. Add shot or other small pieces of metal until the cup will just float without dipping water. Remove the loaded cup, dry it, and weigh it with its contents. What weight of water was displaced by the loaded cup? How do you know? How great a buoyant force was acting to cause the loaded cup to float? How is it possible for bodies heavier than water to float?

Why do steel vessels float? Many persons wonder why a vessel such as a warship built of steel and weighing hundreds of tons will float. Every one knows that a mass of iron, steel, or tin sinks quickly in water. However, if a mass of metal were made in the form of the hull of a ship, it would float on water just as the tin cup floated in Experiment 43. In that experiment we learned that the cup with the shot displaced a weight of water equal to the combined weight of the cup and the shot. The shape of the hull of every steel vessel is such that it displaces enough water so that the weight of the water displaced more than equals the weight of the steel vessel and its load. If a ship loaded with all it is capable of carrying weighs 10,000 tons, the hull has been so constructed that it will displace somewhat more than 10,000 tons of water. In other words, a loaded steel vessel is buoyed up by a force equal to the weight of the water it displaces.

Why can a submarine travel under water? A submarine never fails to stir our interest. How is it possible for a submarine to disappear below the surface of the water, to forge ahead when entirely submerged, to rise again, and to glide along the surface? The principle upon which the submarine operates is the principle stated in the law of Archimedes.

When a submarine is "standing still," or gliding along at the surface of the water, it displaces its own weight of water. When the order to submerge is given, specially prepared tanks which are at the bottom of the submarine open and water enters them, thus increasing the weight of the submarine. Water is let into the tanks until the combined weight of this water and the submarine brings the top of the vessel down nearly to the surface of the water. When the submarine is under headway at this level, it can be sent below the surface by means of a diving rudder. This rudder is also used to bring the submarine up to the surface again. Explain how the rudder works. Compare its action with the way in which a swimmer can use his arms to force his body under water.

When necessary to submerge more rapidly than is possible by the use of the rudder alone, still more water can be let into the tanks, thus making the combined weight of the submarine and the water in the tanks greater than the water displaced.

When the order is given for the submarine to rise to the surface, compressed air forces its way into the tanks and drives out part of the water, thus lightening the submarine sufficiently for the buoyant force of the water displaced to raise it to the surface.

PROBLEM: HOW IS WATER USED AS A UNIT OF MEASUREMENT?

Have you ever thought how much less you seemed to weigh when you were in water? You could stand on tiptoe with very little effort; you seemed to have hardly any weight at all. Perhaps you have noticed that you could pick up and move heavy stones under water that you could not budge on land. This apparent loss of weight is easily explained if you remember the principle of Archimedes: A body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced.

Experiment 44. To show why a body seems to weigh less when immersed in water. Suspend a piece of iron from a spring balance (Fig. 71). What is its weight in air? While still suspended from the balance, immerse the iron in water. What is its weight in water? How much weight has the iron appeared to lose? This apparent loss of weight must, by Archimedes' principle, be equal to the weight of the water displaced. What, then, is the weight of the water displaced by the iron?

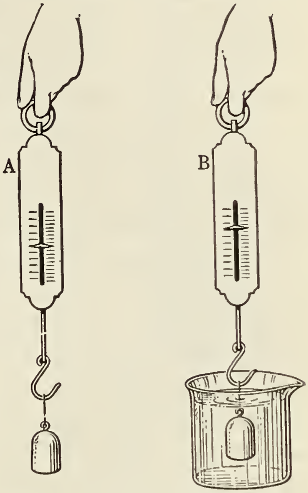


FIG. 71. Does the weight of an object in air differ from its weight in water? Why?

Special problem. The weight of a certain kind of stone is 168 pounds per cubic foot. If a cubic foot of this stone were immersed in water, how much water would be displaced? What would be the weight of this water? How much would the cubic foot of stone appear to weigh?

The comparison of weights—density. We often need to know whether a given volume of one substance weighs more or less than an equal volume of another. That is what we mean when we ask, is platinum heavier than gold or, is iron as heavy as copper? The answers to such questions may be found in the following table.

The Densities of a Few Common Substances
(In grams per cubic centimeter)

Alcohol	0.79	Gasoline	0.68	Olive Oil	0.9
Aluminum	2.7	Iron (cast)	7.4	Platinum	21.37
Copper	8.9	Gold	19.3	Silver	10.5
Cork	0.25	Mercury	13.6	Zinc	7.1

For example, the density of platinum is 21.37 grams per cubic centimeter. This statement means that a piece of platinum 1 cubic centimeter in volume weighs 21.37 grams. From the table find the weight of one cubic centimeter of gold; of copper.

The *density* of a substance may be defined as the weight of a unit volume of that substance.

In the metric system the density of a substance is the weight of a cubic centimeter (a unit volume) of that substance; in the English system the density of a substance is the weight of a cubic foot (a unit volume) of that substance.

You know that a cubic foot of water weighs 62.4 pounds. What is the density of water in the English system? A cubic foot of copper weighs 555.36 pounds. What is the density of copper in the English system? If a cubic centimeter of gold weighs 19.3 grams, what is the density of gold in the metric system?

How to find the density of a substance. If you know the weight (*mass*) of a substance and its volume, you can find the density by dividing the mass by the volume. You must be careful, however, to express the weight and volume in units of the same system. If the weight is in pounds, how must the volume be expressed? If the volume is in cubic centimeters, how must the weight be expressed?

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad \text{that is, } D = \frac{M}{V}$$

Special problem. If 15 cubic feet of a substance weighs 75 pounds, what is the density of the substance?

How can the volume of an irregular solid be measured? An insoluble solid having an irregular shape can be weighed, but its volume cannot be found by direct measurement. It can, however, be found by the indirect measurements made in the following experiment.

Experiment 45. To measure the volume of an irregular insoluble solid. Pour water into a glass cylinder having a scale marked in cubic centimeters (Fig. 72). If the surface of the water is at the 35 cc. mark, how many cubic centimeters of water are in the cylinder? Put into the water the irregular solid, a small stone. What happens to the surface of the water? If it now stands at 42.5 cc., what is the volume of the stone?

Which system must be used on the scale of a cylinder if you needed to find the number of cubic inches in a solid by this method?

How can water be used to find the density of a substance? The density of a substance in the metric system can be found by another method. This method makes use of the fact that one cubic centimeter of water at 0° C. weighs one gram. You know that when a substance is weighed first in air and then in water, there is an apparent loss of weight equal to the weight of the water displaced.

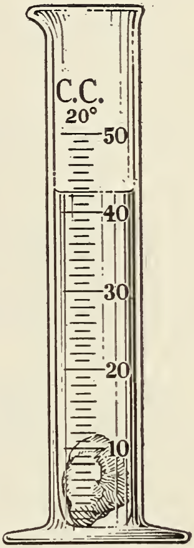


Fig. 72. Tell how this graduated cylinder may be used to measure the volume of an irregularly shaped object.

For example, suppose a piece of iron weighs 74 grams in air and 64 grams in water. The apparent loss of 10 grams is equal to the weight of the water displaced. That is, 10 grams of water have been displaced. But 10 grams of water occupy 10 cubic centimeters of space. Hence the iron must have had a volume of 10 cubic centimeters. If 74 grams of iron have a volume of 10 cubic centimeters, the density of iron must be 74 ÷ 10 or 7.4. Does this agree with the density of iron given in the table?

In the metric system, the density of a substance may be found by dividing its weight in air by its apparent loss of weight in water.

Special problems. A series of interesting experiments can be performed with mercury, oil, water, and small pieces of different metals which will show how these substances differ in density.

To arrange oil, water, and mercury in layers. Pour mercury into a small test tube until the tube is about one-fourth full. Then pour in about the same volume of water colored with red ink. Finally, add an equal volume of oil. Do the liquids remain in layers? Shake the test tube gently; then allow the liquids to settle. What happens? Which of these three substances has the greatest density? The least? How do you know?

To show that certain metals will float on mercury. Fill a small evaporating dish about half full of mercury. Place on the mercury, one at a time a steel paper clip, a small key, and other articles made of metal. Do they sink or float? Explain why.

Place on the mercury in turn a cent, a nickel, a dime, and a quarter. What metal or metals is each of these coins made of? Do they sink or float? Why?

From the table of densities page 108 select the metals that will float on mercury. Are there any that will sink in mercury? What are they? Tell whether olive oil will float on gasoline. Is the density of a substance that will float on a liquid greater or less than the density of the liquid? Test your conclusion.

Water as a standard of measurement—specific gravity. The ratio of the weight of a substance to the weight of an equal volume of water is called the *specific gravity* of that substance. The weight of a cubic foot of copper is 555.36 pounds and the weight of a cubic foot of water is 62.4 pounds. Hence, the specific gravity of copper is 555.36 ÷ 62.4, that is, 8.9. The weight of one cubic centimeter of copper is 8.9 grams; the weight of one cubic centimeter of water is 1 gram. Hence the specific gravity of copper is 8.9 ÷ 1, that is, 8.9. How does the specific gravity of copper in the English system compare with the specific gravity of copper in the metric system? The specific gravity of a substance is the same in either the English or the metric system.

You have just found that the specific gravity of copper is 8.9. Find from the table the density of copper in the metric system. How do these compare? In the metric system the number used for the specific gravity of a substance is the same as the number that tells what the density of that substance is. But the density of the substance is expressed in grams per cubic centimeter while its specific gravity is a number.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

Archimedes
buoyant
density
floating
force
hydraulic
immersed
principle
specific gravity
mass
submarine
suspended
syringe
transmission
volume

Write the number of each item on your paper and after it the word that completes the statement.

1. One cubic foot of water weighs ________ pounds.

2. The pressure on the bottom of a tank of water 8 feet wide, 10 feet long and 5 feet deep is ________ pounds.

3. To calculate the pressure on the side of a vessel of water the ________ depth must be used.

4. A cubic foot of cast iron weighs ________ pounds.

5. The formula for finding the density of a substance is ________.

6. Pressure applied to an enclosed liquid is transmitted ________ in all directions.

7. If oil, water, and mercury are poured into a vessel and allowed to stand, ________ would be found between the other two liquids.

Which item in each of the following lists does not belong with the others?

8. depth; weight; waves; water pressure; area.

9. pistons; Pascal; hydraulic press; brakes; Torricelli.

10. velocity; density; volume; weight; mass.

Which of these statements are true? If any are false, re-state them in correct form.

11. Pressure of water at a given depth is greater downward than upward.

12. A ship which weighs about 10,000 tons displaces about 10,000 cubic feet of water.

13. A body immersed in water is buoyed up by a force equal to the weight of the water it displaces.

14. The buoyant force of water hinders the upward movement of a submarine when it is rising to the surface.

15. A cubic foot of silver is lighter than a cubic foot of iron.

THOUGHT EXERCISES FOR UNIT III

Principles of Science

State in a sentence each of the scientific principles found in this unit. One of them is: The density of a substance is equal to its mass divided by its volume.

Questions or Problems

1. Why is it necessary to treat filtered water with chlorine?

2. Why does boiling make water safe to drink?

3. How can hard water be changed into soft water?

4. What does some water contain that makes it unfit for drinking purposes?

5. What is the gray coating on the inside of a teakettle? This substance on the inside of a steam boiler affects the boiler in what way?

6. Why are traps a necessary part of the plumbing in a house?

7. Why is alcohol added to the water in an automobile radiator in winter?

8. Why is brine used as a freezing solution in the manufacture of ice?

9. How are the processes of evaporation and condensation continually changing the atmosphere?

10. Why is it necessary for the captain of a submarine to watch the depth gauge carefully when traveling from out in the ocean toward the mouth of a river?

11. The area of the small piston of a hydraulic press is one square foot and the area of the large piston is twenty square feet. How much weight can be lifted on the large piston by a force of two hundred pounds acting on the small piston?

12. A man found a lump of metal. He discovered it had a volume of five cubic centimeters and weighed 52.5 grams. What was the metal?

Projects and Reports

1. Study at first hand the water supply system of your community and make a report upon: (1) the capacity of the plant in gallons per day;

(2) method of securing water pressure; (3) methods of purification and their effectiveness and whether you consider the system satisfactory.

2. Make a study of the water supply systems of several country homes. Report on: (1) the source of water; (2) methods of purification (if any); and (3) methods of securing water pressure.

3. Look up and report upon the methods of sewage disposal used by some of our large cities. Indicate in your report which method, in your opinion, is the most satisfactory one.

4. Test some water to determine whether it is hard or soft. Demonstrate with soap before the class.

5. Set up a distillation apparatus and separate alcohol from a solution of alcohol and water. Demonstrate before the class. Alcohol will continue to burn when ignited. Test the distilled alcohol to determine whether it will burn.

6. Study the life of Archimedes and report to class. Show that his discoveries have a relation to this unit.

7. The gasoline gauges on certain kinds of automobiles are hydraulic. Go to a garage and with a mechanic observe how such a gauge is made. Make a full report to the class.

8. Go to a service station where cars are lifted up on a greasing rack. Study with the service man the method of lifting the cars, and make a report to the class.

9. Learn to read your water meter.

REFERENCES FOR READING AND STUDY

1. Althouse and Turnquist, *Modern Electric and Gas Refrigeration.* The Goodheart-Wilcox Company, Chicago.

2. Broadhurst, Jean, and Lerrigo, Marion Olive, *Health Horizons,* Chapters 21 and 23. Silver Burdett Company.

3. Bishop, Furnham, *The Story of the Submarine.* D. Appleton-Century Company.

4. Cambridge University Press, *A Little Book on Water Supply.*

5. Cochrane, J. A., *School History of Science.* Edward Arnold & Company.

6. Darrow, F. L., *Thinkers and Doers,* Chapter XXII. Silver Burdett Company.

7. Harrigan, Paul D., *A B C of Air Conditioning.* Gernsback Publications, Inc., New York.

8. Holloway, Hope, *The Story of Water Supply.* Harper & Brothers.
9. Lipman, J. G., *Bacteria in Relation to Country Life.* The Macmillan Company.
10. Lynde, C. J., *Everyday Physics*, Chapter IV. The Macmillan Company.
11. Meister, Morris, *Water and Air*, Chaps. I to VI. Charles Scribner's Sons.
12. Prudden, T. M., *Drinking Water and Ice Supplies.* G. P. Putnam's Sons.
13. Russell and Yonge, *The Seas*, pp. 1–13. Frederick, Warne & Company, Ltd.
14. Thompson, J. M., *Water Wonders Every Child Should Know.* Doubleday, Doran.
15. Verrill, A. H., *The Ocean and Its Mysteries*, Chapters I and II. Dodd Meade & Company.

UNIT IV

HOW DO WEATHER AND CLIMATE AFFECT OUR LIVES?

Exploring Weather and Climate

Have you ever thought it strange or amusing that people talk so frequently about the weather? If you consider how the health and happiness of people depend directly upon the weather, you will not be so surprised to hear this subject discussed daily. Let us notice some examples. Before transportation and refrigeration were conducted so efficiently, a great snow storm would cause food prices in cities to rise rapidly in a period of a few days. An approaching storm may contain moisture needed badly by livestock and growing crops, but its passage may destroy crops and kill cattle which would have supplied people with part of their food and clothing. The prosperity and happiness of our country depend largely upon the movement of storms across it. On the other hand, these same storms may be so destructive that they destroy the prosperity and lessen greatly the happiness of people. Do you still think it strange that so much time is spent in discussing the weather?

Weather conditions are not the result of accident. They are caused by the evaporation of water and by gigantic currents set up in the atmosphere in which we live and by heat from the sun. You have already learned that water vapor is constantly passing into the air. You no doubt have heard the expression "Whatever goes up is sure to come down." No doubt you would like to understand what happens high up in the atmosphere to bring this water vapor back to the surface of the earth as rain, snow, sleet, and ice. Scientists who have investigated storms have found that they are due to certain definite causes which are fairly well known.

Have you ever wondered why a storm that a radio announcer said was coming to your locality did not appear? On the other hand, many times when a storm is predicted it arrives as punctual as a train that is announced in a railway station. Perhaps you may think weather forecasts are just shrewd guesses, but they are not. They are based upon scientific observations. This unit will answer many questions concerning storms, weather forecasting and many others concerning weather and climate.

CHAPTER IX

HOW DO CLIMATE AND CHANGES IN WEATHER AFFECT OUR DAILY LIVES?

Do you know:

Why we talk about weather oftener than about any other topic? The difference between weather and climate? How weather affects your daily life? Why people build houses? How your food, clothing, and shelter depend upon the weather?

That the temperature may be below freezing at the equator? Why fruit is raised in the region around the Great Lakes? Why towns on the sea are cooler in summer than inland towns in the same latitude and not much above sea level?

PROBLEM: HOW DO WEATHER CONDITIONS AFFECT OUR DAILY LIVES?

What is weather, and what is climate? When we say that the weather is "fair," we mean that the sky is more or less clear and the atmosphere calm and agreeable. On other days we may say the weather is cloudy, stormy, or disagreeable. The condition of the atmosphere with respect to moisture, air pressure, temperature, and winds, on a particular day or for several days, we refer to as the weather. The average condition of the atmosphere in a region over a period of time, say for a number of years, we speak of as the climate of that region. Hence, we say the climate of a region is hot, temperate, cold, moist, or dry. Weather and climatic conditions affect nearly every phase of our life.

How does our food supply depend upon weather? The production of materials used for food is directly affected by weather. If the blossoms of fruit trees in a region are injured or killed by frost, little or no fruit may be produced there that year. Fruit may be shaken from trees or bushes by storms. Continued dry

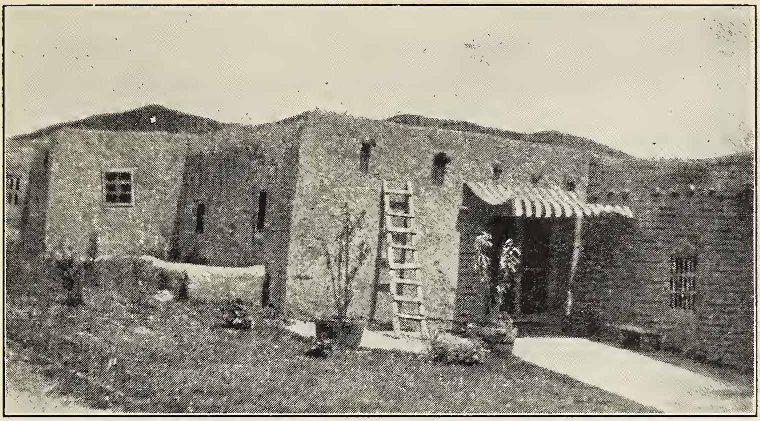


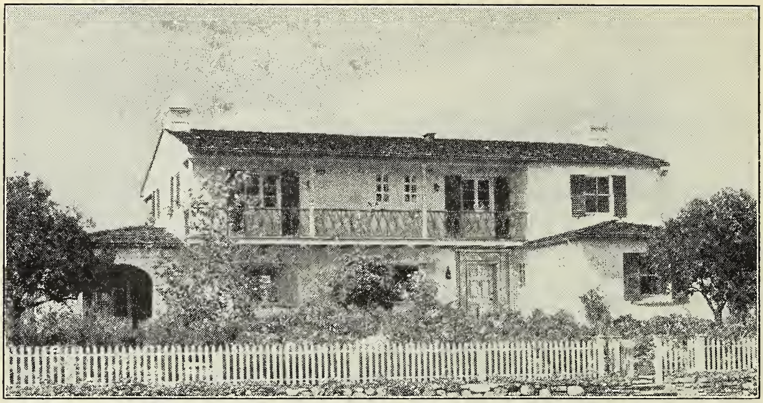
Photo by C. E. Sipprell *Courtesy The House Beautiful*

FIG. 73. An adobe house in Santa Fé, New Mexico. In this region neither stone nor timber is readily available, and therefore adobe is used in building many houses. This house, like many others in the Southwest, is built around an open court, a patio. The walls are thick and are built higher than the flat roof. Explain how such a house is well adapted to a hot, dry region.

weather may prevent grains and other crops from producing a normal yield, while too much moisture may injure them.

On the other hand, the seasonal warmth of spring is necessary to develop the buds on trees and vines and to sprout the seeds sown in the earth. Rains furnish the moisture, and the sun the light and heat, all three of which plants use in manufacturing food for their growth and in developing fruits, grains, and other products used by man. All plant life depends upon weather conditions favorable for its growth.

There are other ways in which our food supply is dependent upon weather. Perishable foods, such as fresh meat, fish, dairy products, fruit and vegetables, will spoil if not kept at temperatures below those prevailing in summer. Furthermore, many domestic animals that might provide us with meat or dairy products are either destroyed or seriously affected every year by blizzards, floods, droughts, and other unfavorable weather conditions.



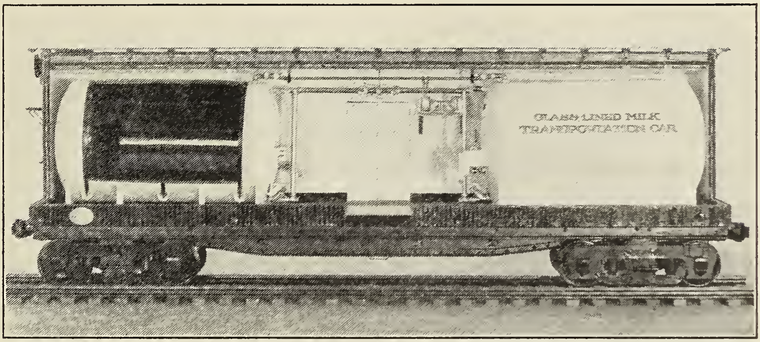
Courtesy The American Home

FIG. 74. When New Englanders went to California, the difference in climate forced them to adapt their native architecture to the warmer climate. What modifications does this house suggest to you? In what ways does it differ from houses in your own locality?

How does our clothing depend upon weather? The production of materials used in the manufacture of clothing is also affected by weather. For instance, weather unfavorable to the growth of cotton or flax might limit the crop so that there would be a shortage of cotton or linen goods. Furthermore, the weather in a particular region has an influence on the type of clothing worn there. If you were to travel in winter from a northern state to Florida or southern California, you would find it desirable when arriving to put on garments of lighter weight. On the other hand, if you were to embark upon a polar expedition, heavy fur clothing would be a necessary item of your equipment.

How does our shelter depend upon the weather? To shield himself from the intense heat of the sun the Arab uses a tent. Dwellers in temperate and frigid belts erect houses to protect them from cold and rain as well as sunlight. In very dry regions houses are built with flat tops (Fig. 73): whereas in very wet regions the houses are built with steep roofs. Can you explain the reason for this? While there may be other reasons, the chief reason men build houses and shelters is to protect themselves from the weather (Fig. 74).

How do work and recreation depend upon weather? Weather may seriously interfere with the daily work of persons employed in agriculture, because most of the labor must be done out of doors. In cities and towns, also, certain industries are affected by weather conditions. Much of the outside work done in the building trades is at a standstill when the weather is stormy or very cold. Plaster dries slowly when there is considerable water vapor in the atmosphere. Road building is seriously hampered by wet weather. Give illustrations of other kinds of work interfered with by weather.



Courtesy American Pfaudler Corporation

Fig. 75. In this modern glass-lined milk transportation car, the walls both of the car and the two tanks are insulated. Milk is cooled before it is run into the tanks, and its temperature is kept about the same during a haul of more than two thousand miles. How?

Weather conditions must be taken into consideration in the transportation and storage of certain kinds of food materials; unless protected against extremes of cold or heat, they may become unfit for use. The increasing use of refrigerator cars (Fig. 75) to transport perishable foods is reducing food losses caused by heat; but, in spite of all the means available for heating cars such foods as apples and potatoes may be frozen while being transported in extremely cold weather.

Communication, whether by mail, telegraph, telephone, or radio, is frequently hindered seriously by storms that sweep over the country.

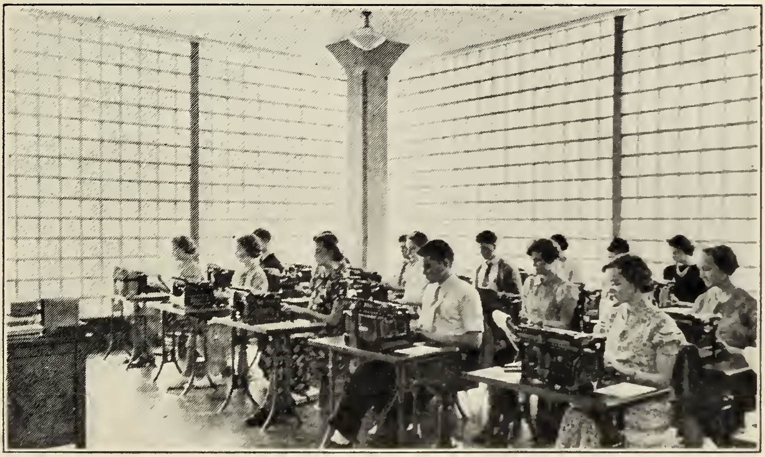
An increased tendency to outdoor recreation causes more people to observe weather conditions than formerly. To be most beneficial and enjoyable, games and sports should take place out of doors and in the sunshine. If they are carried on under unfavorable weather conditions such as rain and cold, the injury to health may outweigh the benefits obtained from taking part in them.

How does climate affect the people in the tropics? In general, each region of the earth has climatic conditions peculiar to itself. In the tropics, except at very high altitudes, the weather is always hot and in most sections the rainfall plentiful. Under such conditions of heat and rainfall, plants grow rapidly and consequently vegetation is abundant. In this region people secure their food supply from plants that grow wild; food crops are seldom cultivated. Because the weather is always hot at sea level, the people need very little shelter; there are almost no houses such as ours.

The people themselves are affected by the heat, and, since it is unnecessary to work much to secure food and shelter, they are inactive and live a very simple life. Consequently the natives of this region have not reached the level of civilization found in the temperate regions of the earth. Scientists believe that the inactivity of these people is due almost entirely to climatic conditions.

How does climate affect the people in the arctic region? The people of the arctic region also have not reached a high level of civilization, due largely to the very cold climate. Here the weather is nearly always cold and there is very little animal and vegetable life compared with that of the tropics. During the short summer plants grow. Some furnish food for reindeer. The people use the flesh and the milk of the reindeer for food and its skin in making clothing and providing shelter; it draws their sledges over the snowy wastes. The other animals of this region are fur-bearing; their furs are used for clothing and their flesh for food. In certain areas food crops are raised. Because of climatic conditions in the arctic region, the people build warm homes. The materials used are chiefly those at hand—stones, turf, skins, and driftwood, snow, and ice. The climate determines the occupations of the people.

How does climate affect the people in the temperate regions? Weather conditions in the temperate regions vary with the seasons (page 194). Name the four seasons. In the parts of the temperate regions having cold weather in winter, the people are obliged to protect themselves with warm clothing and shelter.



Courtesy Supt. of Public Schools, Elkader, Iowa

FIG. 76. An air-conditioning plant keeps the "weather" in this school room just right for the best working conditions and health of the students. The walls are made of glass.

Upon the approach of milder weather people change their clothing to meet the warmer weather conditions. In many parts of the temperate regions, due to the fertile soil, and the heat and rainfall of summer, abundant crops may be raised; agriculture is therefore one of the leading occupations. Many industries employing thousands of people are engaged in preserving the food grown in summer for use during the winter. Would this be necessary in the tropics?

Forests, too, are widespread, providing a basis for many occupations. Climatic conditions are favorable for transportation, mining, building, the construction of highways, and many other occupations. Industries which provide for the comfort and ease of the people have been developed to a high degree of efficiency (Fig. 76). The inhabitants of the temperate regions are energetic. They have developed a high type of civilization. Scientists believe that the activity of people in these regions is due largely to the invigorating climate.

PROBLEM: WHAT DETERMINES THE CLIMATE AND WEATHER OF A REGION?

Does altitude affect climatic conditions? In the Andes Mountains of South America there are snow-capped peaks even near the equator. What is the reason for this? While going from the seashore to the top of one of these peaks, a traveler may experience nearly all the kinds of climatic conditions he would encounter on a trip from the equator to the north pole. At the seashore the climate is, of course, that of the tropics. As he proceeds on his way he encounters climatic conditions similar to those of the temperate and arctic regions. As you might suspect, the plants and animals at each of these successive altitudes are very similar to those found in other regions north or south of the equator, having a corresponding climate.

Likewise it is possible in the Rocky Mountains of North America and in the mountainous regions of other parts of the earth to travel in a few hours from summer's heat to a region of perpetual cold. Have you ever had this experience? What do you conclude about the effect of altitude on climatic conditions?

Do ocean currents affect climatic conditions? Ocean currents, too, affect the climate of many countries. The British Isles and northwestern Europe would have long, cold winters if the prevailing winds did not carry air warmed by the Gulf Stream to their shores. The Gulf Stream has little effect on the climate of the eastern part of the United States because the prevailing westerly winds carry the air warmed by the Gulf Stream eastward. The climate of the western coast of North America, even in southern Alaska, is greatly modified by the warm winds which blow eastward from over the Japan Current in the Pacific.

Explain what effect a cold ocean current would have on climate.

Do large bodies of water affect climatic conditions? The temperature of land rises more rapidly under the heat of the sun than the temperature of a nearby body of water, because it takes about five times as much heat to raise the temperature of a given volume of water 1° as it does to raise the temperature of an equal volume of land 1°. For this reason it takes some time in the spring for the sun to warm a lake sufficiently for swimming, even though the surface of the land surrounding the lake may have become quite warm. For the same reason the cooler spring weather prevailing in places near bodies of water, prevents the flowering of fruit trees until the season of killing frosts is past.

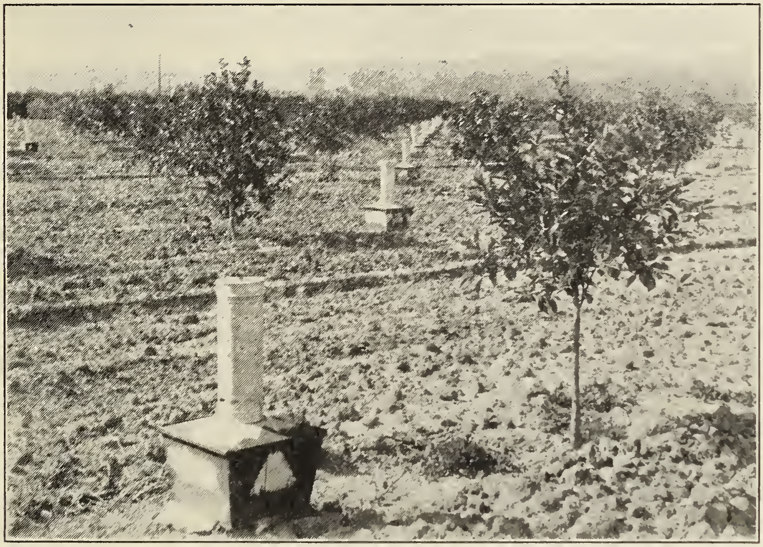


FIG. 77. No longer is it necessary to depend entirely on climate in the raising of fruit. Oil heaters such as the ones shown in this orange grove in southern California protect the trees from damage by frost. By using forty or fifty heaters to the acre it is possible to raise the temperature as much as ten degrees.

Substances that become heated quickly also give up heat quickly. Therefore, since land becomes heated more quickly than water, it also cools off more quickly. Accordingly, a body of water which has become heated during the summer, loses its heat so gradually that the surrounding region during the autumn months is warmer than localities farther inland in the same latitude. Owing to these conditions, early frosts are prevented in the fall. Of course the above statements do not hold true unless the prevailing winds blow from the water over the land. In general, however, a large body of water tends to prevent extremes of heat or cold in the weather of the surrounding region.

In the interior of the continents, there are greater extremes of heat and cold than in the corresponding latitudes nearer the sea. How would you account for this?

How do land and sea breezes affect climatic conditions? Land and sea breezes occur along the coasts of large bodies of water. During the daytime the land is heated more rapidly than the water. As a result the air over the land is warmer and lighter than the air over the water. Consequently the air over the water moves towards the land, forces the warmer air up, and takes its place. This movement of cooler air from over a body of water toward and over land is called a *sea breeze;* it blows during the day and usually reaches its greatest velocity in late afternoon.

During the night the land cools more rapidly than the water, with the result that in a short time the water is warmer. The warmer air over the water expands and becomes lighter, and the heavier air from over the land moves toward and over the water, forces the warmer air up, and takes its place. This movement of cooler air from over land toward and over a body of water is called a *land breeze.* It blows during the night and usually reaches its greatest velocity toward morning.

These breezes encourage people in temperate climates to seek the shores of large bodies of water during the hot summer months. You are not to suppose, however, that they blow daily in summer for they are often overcome by great storms which sweep across the country.

From what you have learned concerning land and sea breezes how would you expect an east wind to affect the temperature in Boston in summer; the temperature in Chicago? A north wind the temperature in Cleveland? A west wind the temperature in Milwaukee?

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

arctic
blizzard
climate
communication
land breeze
recreation
sea breeze
temperate
tropics
unfavorable
variation
vegetation

Write the number of each item on your paper, and after it the word or phrase that completes the statement.

1. Out door sports are most beneficial when played in rain; snow; fog; wind; sunshine.

2. People talk about the weather because: the weather is always "good"; the weather is always "bad"; the weather is an important factor in their lives; many people are never influenced by the weather.

3. People like to go to the sea shore during hot weather because: living is cheaper there; they always find agreeable companions; the fishing is always good; sea breezes cool the air; the sun is cooler there.

4. Farmers get weather reports because: they are interesting reading; their children like the pictures; they are inexpensive; they are a guide for the farmer in his work; they take the place of a clock in the home.

Which of these statements are true? If any are false, re-state them in correct form.

5. Sea breezes usually blow during the night.

6. There are no snow covered mountain peaks in the torrid zone.

7. Weather conditions in the temperate zone are governed largely by the "change of seasons."

8. The kind of house that a man builds depends upon climatic conditions.

9. Climatic conditions depend largely upon altitude.

10. The winters in England are colder than the winters in New York.

CHAPTER X

WHAT MAKES THE WEATHER CHANGE?

Do you know:

That the air in a heated room in winter may be as dry as the air over a desert? That dew does not fall? How frost is formed? What a cloud is? How a cloud is formed? That snow is a form of rainfall? How rainfall is measured?

What causes winds? How a cyclone travels? Why lightning rods are used? That a tornado at sea sometimes whips up a column of water almost a mile high?

PROBLEM: HOW DO CHANGES IN TEMPERATURE AND IN THE AMOUNT OF MOISTURE IN THE AIR MAKE THE WEATHER CHANGE?

In Chapter IX you learned that weather affects almost every activity of your daily life. A study of weather becomes fascinating when one realizes that scientific principles underlie the changes from a clear sky to clouds and rain, from clouds and rain to a clear sky, and from a calm to a raging storm.

What is humidity? The amount of water vapor in air is called *humidity*. It affects weather greatly. Even though the sky is clear, the atmosphere may contain considerable water vapor, but we cannot see it because it is invisible. If the temperature should drop, this water vapor may be condensed until clouds are formed. From these clouds the water may fall to the earth as rain, snow, sleet, or hail. If air contains much water vapor, it feels damp and we say the humidity is "high." If air contains little water vapor, it feels dry and we say the humidity is "low."

You have learned that the air at a given place does not contain the same amount of water vapor at all times, and that, as the temperature of air rises, its capacity to hold water vapor increases. You know, too, that a cubic meter of air can contain not more than 4.8 grams of water vapor at 0° C. (32° F.) and not more than 17.1 grams of water vapor at 20° C. (68° F.), (page 93). When a given volume of air at a certain temperature contains all the water vapor it can hold at that temperature, it is said to be *saturated.* How many grams of water does it take to saturate a cubic meter of air at 0° C.? At 20° C.? In what way is saturated air like a saturated solution (page 89)?

Although the air at a given place may not be saturated with water vapor, if the temperature falls and continues to fall, the air will finally become saturated; if the temperature continues to fall after the air is saturated, the water vapor will condense into dew, rain, frost, or snow, depending on the drop in temperature. But should the temperature of air be rising, its capacity for holding water vapor is increased. If, under these conditions, it is not possible for the air to acquire more water vapor, the air will become drier because of its increased capacity to hold water vapor even though there is still the same amount of water vapor in the air. Under these conditions, dew, rain, frost, or snow could not be formed.

What is relative humidity and how does it affect us? Before we can tell how relative humidity affects us, we must know what it is. The ratio of the amount of water vapor present in air at a certain temperature to the amount of water vapor necessary to saturate it at that temperature is called *relative humidity.* Relative humidity is stated as a per cent. A relative humidity of 60 per cent means that at a given temperature air contains 60 per cent of the water vapor required to saturate it at that temperature. A relative humidity of 100 per cent at a given temperature means that air contains 100 per cent of the water vapor required to saturate it at that temperature; in other words, it is saturated. For comfort and health, the relative humidity of air should be about 55 per cent.

In winter the relative humidity of the air in a room heated by steam, hot water, or hot air to a temperature of 70° is often as low as 25 to 30 per cent. Its relative humidity is lower than that of air over a desert, consequently in such air perspiration from a person's body evaporates rapidly, causing him to feel cold. Why? To offset this effect on the body, such a room must be kept at a higher temperature than would be necessary if the relative humidity were at about 55 per cent. Would this require more fuel than necessary? Explain.

On the other hand, when the relative humidity of air in a room is higher than normal (55 per cent), it contains so much water vapor that the perspiration from the body evaporates slowly, causing a feeling of discomfort. Why?

Experiment 46. To determine the per cent of water vapor in the air. If a regular laboratory hygrometer is not available, make one from two thermometers. Around the bulb of one of the thermometers tie a very thin piece of cotton or one thickness of linen. Wet the cotton or linen with water. Fan both the wet and dry thermometers until there is no further change in the readings during the last minute of fanning. What temperature does the dry thermometer record? The wet thermometer? How many degrees difference is there between the readings of the two thermometers?

Locate the difference between the two thermometer readings in the top row of the table given below. Run your finger down this column until you come to the number which is in a horizontal line with the reading of the dry thermometer. What is the number? This number is the per cent of water vapor in the air, that is, the relative humidity of the air.

Reading of dry thermometer F.	*Difference between dry and wet thermometers in degrees*									
	2	4	6	8	10	12	14	16	18	20
	Relative humidity									
65	90	80	70	61	52	44	35	28	20	13
66	90	80	71	61	53	45	36	29	22	14
67	90	80	71	62	53	45	37	30	23	16
68	90	81	71	63	54	46	38	31	24	17
69	90	81	72	63	55	47	39	32	25	18
70	90	81	72	64	55	48	40	33	26	19
71	91	81	72	64	56	48	41	34	27	20
72	91	82	73	65	57	49	42	35	28	22
73	91	82	73	65	57	50	42	35	29	22
74	91	82	74	66	58	50	43	36	30	23
75	91	82	74	66	58	51	44	37	31	24

Experiment 47. To show how dew is formed. Pour water into a polished metal cup or a small glass beaker until it is about two-thirds full. Add ice slowly, stirring the water with a thermometer. What forms on the outside of the cup? Where does it come from? The temperature of the metal cup or beaker has fallen until water vapor from the air condensed into drops of water on the outside of the cup.

The temperature at which drops of water begin to form from water vapor in air is the *dew point* of the air.

How is dew formed? Dew forms in much the same way as the drops of water formed on the outside of the cup in Experiment 47. During the day when the sun is shining the air is warmed and its capacity for holding water vapor is increased. During the night, the land gives off heat rapidly. Consequently its temperature falls. The air close to the earth is cooled, and if its capacity for holding water vapor is reduced enough, the dew point is reached. At this temperature, the water vapor in the air near the earth condenses and collects as water on grass, bushes, and other objects near the earth. This water is known as *dew*.

How is frost formed? If the dew point is lower than the freezing point of water, and the temperature falls below this dew point, the water vapor in the air is deposited on vegetation and other objects as ice crystals. These ice crystals are known as *frost*.

How are clouds formed? So far we have considered only the invisible form of moisture in the atmosphere known as water vapor. Now we shall study the visible forms, clouds, rain, hail, sleet, and snow.

Experiment 48. To show how a cloud forms. Set up the apparatus shown in Figure 78. Put some water in the flask. Boil the water. Observe the cloud of moisture rising a short distance above the top of the glass tube. Where must the moisture have come from? Why couldn't you see it in the flask? In the tube? Right at the mouth of the tube?

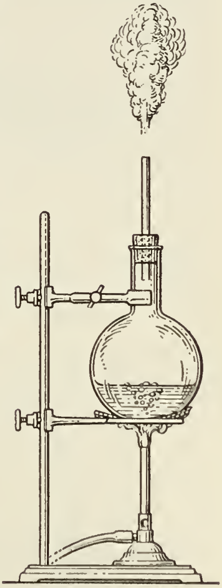


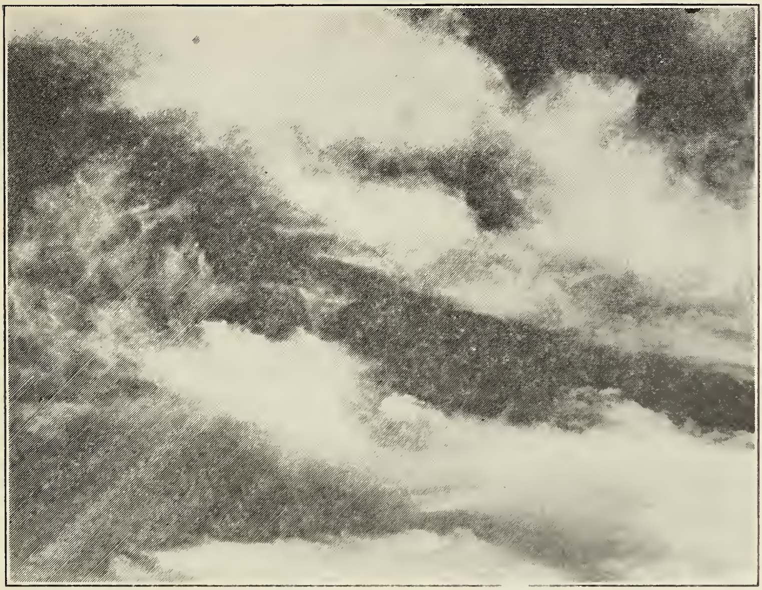
Fig. 78. How was the cloud shown in this drawing formed?

The steam (i.e., water vapor at a temperature of 212° F.) which filled the flask and passed up through the tube could be seen only after it had been for a time in contact with air at a much lower temperature than 212° F. After sufficient steam had escaped, enough water vapor was added to the air above the tube to saturate it; as a result some of the steam was condensed into minute droplets of water. These droplets formed the small cloud which you can see above the tube (Fig. 78). You observed that the moisture remained as a cloud for only a very short time. It disappeared because the circulation of the air soon carried the droplets into air that was not saturated with water vapor; here the droplets evaporated into water vapor and so became invisible.

If, however, a large amount of steam is produced, drops of water condense on various objects in the room. Can you tell why this happens? If the room is small, you may notice that, after the amount of water vapor in the air has been increased, the steam cloud remains suspended over the flask for a longer time.

Clouds are formed in the air in a way somewhat similar to that in which invisible steam in Experiment 48 is condensed into visible droplets of water. Invisible water vapor in the atmosphere is lighter than air; consequently it rises higher and higher until it reaches air of the same weight. Here the air is cooler. As large quantities of water vapor reach this cool air, they increase the amount of water vapor in the cooler air to the saturation point; condensation begins to take place and continues to do so until great clusters of tiny droplets of water are visible. This visible moisture is called a *cloud.* A cloud near the earth is called a *fog.* Like the tiny cloud above the flask a rain cloud may be carried into a drier or warmer layer of air, where the droplets of water change into water vapor, thus becoming invisible. In reality clouds are the visible caps of columns of invisible water vapor reaching upward from the earth.

Are clouds formed by changes in atmospheric pressure? In Unit I we learned that changes in atmospheric pressure are indicated by the "rising" or "falling" of a barometer. Observations indicate that changes in atmospheric pressure are often accompanied by cloud formations.



Courtesy U. S. Weather Bureau

FIG. 79. Cirrus clouds. The water in cirrus clouds is in what form?

Experiment 49. To show that water vapor condenses into droplets of water when the air pressure is reduced. Set up the apparatus shown in Figure 80. Fill a 2-liter acid bottle *A* about one-half full of water. Fit a one-hole rubber stopper *C* into the bottle and connect an exhaust pump. As air is being pumped from the bottle, the remaining air expands to fill the space above the water; consequently the pressure of the air in the bottle will be reduced. Why?

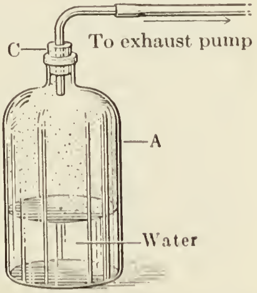
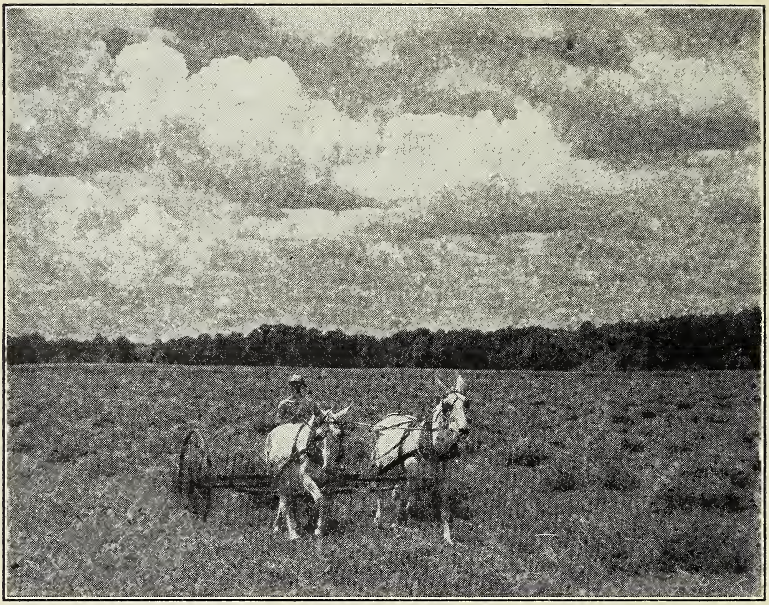


FIG. 80. How was the cloud in the bottle formed?

Operate the pump and notice carefully what is formed in the space above the water. After a few strokes a light fog (cloud) will be seen to form. What do you think caused the fog (cloud) to form? From your observations during this experiment, can you suggest one way in which a cloud may be formed?

Since water vapor condenses when the air pressure is reduced, we can sometimes foretell an approaching storm by watching a



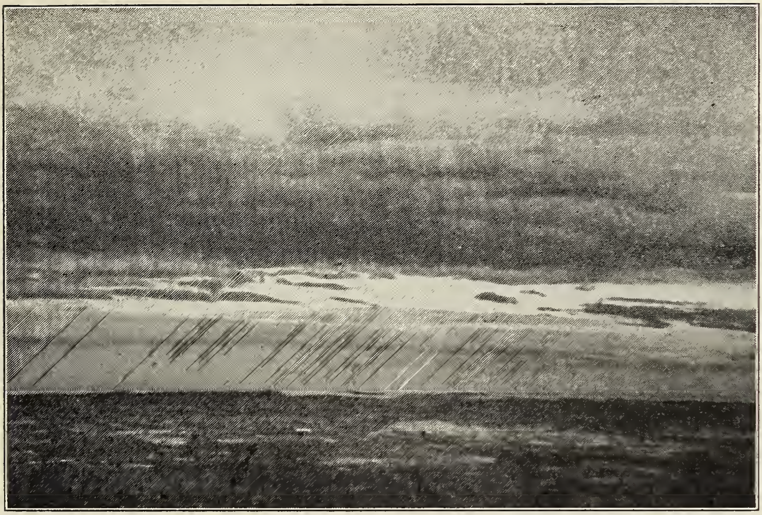
J. C. Allen and Son

FIG. 81. Cumulus clouds. Why are some light and some dark?

barometer. If the barometer is falling rapidly, would you expect a storm? If it is raining and the barometer starts to rise, would you expect the storm to end in a short time? Why?

Experiment 50. To give another illustration of condensation when air pressure is reduced. Bring to class a bottle of pop or ginger ale. Notice carefully whether there is a cloud or fog in the neck of the bottle above the liquid. Remove the cap from the bottle, being careful not to disturb the liquid. Did a cloud form in the space above the liquid in the neck of the bottle? Was the pressure over the liquid increased or decreased when the cap was removed? How is the change in pressure related to the formation of the cloud?

The forms and appearances of clouds. Although all clouds are masses of condensed water vapor, they differ in form and appearance. Clouds are named according to their appearances. Make a careful study of the light and dark shades, the form, and the texture of the clouds shown in Figures 79, 81, 82, and 83.



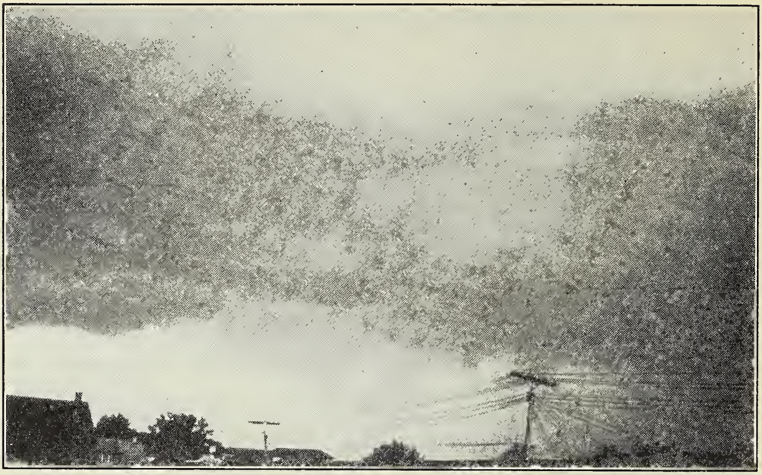
Courtesy U. S. Weather Bureau

FIG. 82. Stratus clouds. Why are they given this name?

From four to eight miles above the surface of the earth, possibly ten miles in the tropics, thin sheets of thread-like clouds form. These are called *cirrus* clouds (Fig. 79). In reality, cirrus clouds are ice clouds because they are composed of ice needles or crystals. It is this kind of cloud that causes a halo around the sun or moon, so often said to be the forerunner of a storm.

The *cumulus* cloud is a thick cloud with a dome-shaped head (Fig. 81). Cumulus clouds frequently loom up in the sky like great mountains. They are formed in somewhat the same way that the little cloud was formed above the flask in Experiment 48. Great columns of air rise into the upper, cooler regions of the atmosphere where their water vapor condenses into innumerable droplets that form these large, fleecy clouds. Their bases are usually horizontal because at this level the invisible water vapor condenses into droplets. Explain. Cumulus clouds are frequently seen on summer afternoons. They may disappear or they may develop into the darker, thicker clouds that precede a thunderstorm.

Stratus clouds (Fig. 82) are frequently seen near the horizon in the late afternoon or early morning. They are flat and sheet-



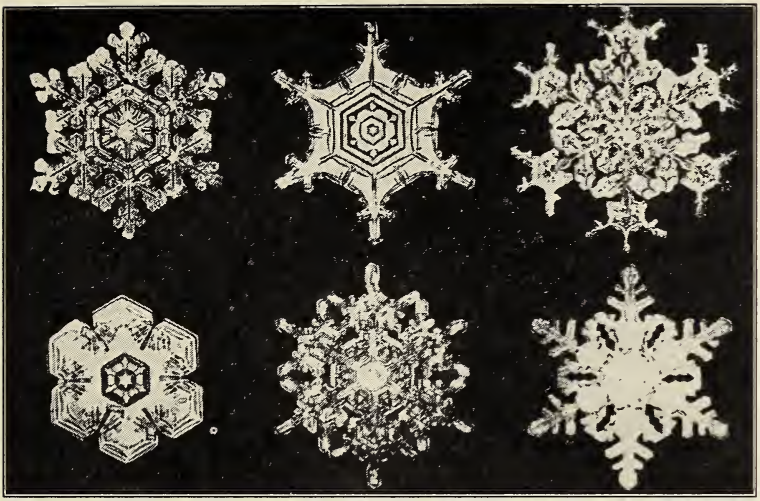
Courtesy U. S. Weather Bureau

FIG. 83. A nimbo-stratus cloud. It is difficult to photograph a nimbo-stratus cloud because it is without contrast either in shape or texture. Rain is falling in the distance.

like. They may stretch out in long narrow bands parallel to the horizon or cover the whole sky.

The dark gray *nimbo-stratus* cloud (Fig. 83) is the one from which rain or snow usually falls. It may cover an area of many thousands of square miles. Its height above the surface of the earth varies with the conditions of the atmosphere. It may be but a few hundred feet above our heads and at other times several thousand feet.

What causes rain? Near the beginning of our study of Unit I, we referred to the tiny particles of dust in the atmosphere. When air containing a considerable amount of water vapor moves into a colder region, the saturation point may be reached and water vapor may be condensed around tiny particles of dust. If the condensation continues, the drops become larger and larger until they will no longer float in the air. They then fall to the earth as rain. It is quite probable that these drops of rain increase in size by combining with smaller droplets of water as they pass through the air on their way to the earth.



Courtesy U. S. Weather Bureau

FIG. 84. Snow crystals. Observe that all the flakes have six principal rays.

How to distinguish different kinds of rainfall. The term "rainfall" includes all forms of precipitation: rain, hail, sleet, snow, dew and frost. With the possible exception of northern Greenland and Antarctica, where only snow falls, there is no region on the earth where it has not rained at one time or another. By *rain,* of course, we mean drops of water that fall upon the earth. Rain may be melted snow and it may range from a drizzle to a downpour.

At temperatures below freezing, water vapor changes directly into snow crystals; that is, water vapor does not first condense into drops of water and then freeze into snow crystals. Catch several snow flakes on a dark cloth and examine them with a magnifying glass. Some are shown in Figure 84. You will observe that these little crystals of ice are very beautiful.

Scientists say that true hail falls only in connection with a thunderstorm occurring usually in warm weather. The theory is that hail forms in the squall (the high wind that comes with a rush as the storm approaches), which occasionally precedes the principal storm cloud. As a drop of water condensed from water vapor passes through a layer of cold air, it is frozen and as it later passes through a warmer layer, it accumulates more water, which may in turn be frozen by passage through another layer of cold air. In this way several successive layers of water and snow may be frozen into one hailstone before it becomes heavy enough to fall to the ground through the whirling upward current of air. This theory seems to explain the fact that hailstones often have several layers of ice and snow. How large were the largest hailstones that you have seen?

Ice that forms on trees when rain falls in freezing weather is not sleet although it is often so called. *Sleet*, as defined by the United States Weather Bureau, is little particles of clear ice that have been formed by the freezing of drops of water on their way to the earth.

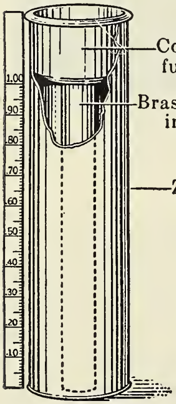


FIG. 85. Rain gauge of the type used by the United States Weather Bureau.

How is rainfall measured? Rainfall is measured in inches by means of a metal rain gauge (Fig. 85). A rain gauge consists of a metal cylinder with a smaller tube inside that widens into a funnel at the top. If the area of the top of the funnel is ten times that of a cross section of the inner tube, one-tenth of an inch of water falling into the funnel fills the tube to a depth of one inch. This makes it possible to tell the amount of rainfall with great accuracy. Why? The water in the rain gauge is measured with a rule graduated in tenths of an inch. In certain rain gauges the scale on the inner glass tube is so marked that rainfall in inches is shown.

If rainfall occurs in the form of snow or ice, the snow or ice melts in the rain gauge and is measured as water. Rainfall in the form of snow cannot be measured as accurately as that which falls as rain. Why?

As a result of weather observation extending over a period of ninety months, the heaviest recorded average yearly rainfall in the world, 455 inches, was reported from one of the Hawaiian Islands. The heaviest recorded average yearly rainfall on the mainland of the United States, not including Alaska, occurred in Tillamock County, Oregon (130 inches). Any region having an average annual rainfall of ten inches or less is considered a desert.

Problem: How Does Heat from the Sun Cause Changes in Weather?

What happens to air when it is heated? Several times thus far in our study of weather, the statement has been made that air is constantly moving from place to place, that light (warm) air is being forced upward by heavier (cooler) air. It is a well-known fact that the warmest place in a heated room is usually near the ceiling. The reason for this is that, when air is heated, it becomes lighter per unit of volume, and consequently it is forced upward by the heavier colder air around it.

Experiment 51. To show what happens to air when it is heated. Balance two empty flasks on a sensitive trip scale (Fig. 86). With a Bunsen burner or an alcohol lamp heat one of the flasks. What is happening to the air in this flask? Watch the scales carefully. What do you observe? What does this change suggest?

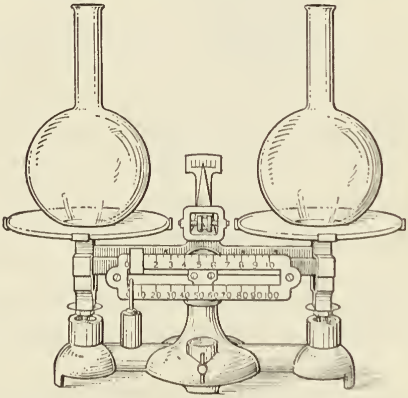


Fig. 86. Does a given volume of heated air weigh more than an equal volume of colder air?

As the air in the flask was heated, it expanded, and some of it escaped from the flask. As a result the air remaining in the flask weighs less than the same volume of air weighed before it was heated. Thus you see that a given volume of air at a certain temperature is lighter than the same volume of air at a lower temperature.

What are winds? In much the same way that the air in the flask was heated with the Bunsen burner, great volumes of air are heated by the sun. As these great volumes of air are heated they expand and become lighter and are forced upward by the cooler surrounding air. When warm air is being forced upward by the cold air surrounding it, horizontal movements of air are set up which rustle the leaves of trees, bend the tall grass, flutter the garments hanging on the clothesline, and move other objects on or near the earth's surface. These movements of air are called winds. They may vary from a gentle breeze to a cyclone or a destructive tornado.

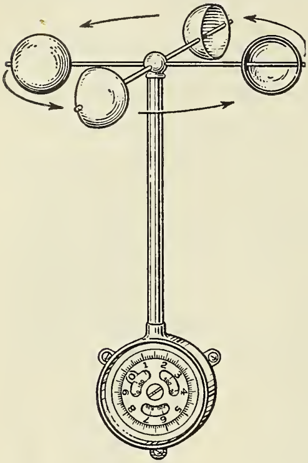


FIG. 87. An anemometer used to measure the velocity of wind in miles per hour.

As you learned in Chapter II, air pressure is measured by a barometer. Warm air is lighter than an equal volume of colder air of the same humidity; consequently in a region of warm air a barometer reading is lower than the reading in a region of cooler air. On a weather map (Fig. 95) the areas of lower air pressure are marked simply "low," and the areas of higher air pressure, "high."

Just as water flows from a higher elevation to a lower one, so winds blow from a region of higher air pressure to one of lower air pressure. The greater the difference in air pressure between the two regions, the greater will be the velocity (speed) of the wind (Fig. 87) toward the region of lower air pressure; just as the greater the difference in the elevation of two points in the course of a river, the swifter will be the current from the upper to the lower elevation.

To summarize:

1. Great volumes of air are heated by the sun.
2. The heated air owing to expansion, becomes lighter, forming an area of low air pressure. The cooler air surrounding the low area is an area of high air pressure.
3. The heavier, cooler air surrounding the lighter, warm air, forces the warm air upward, causing movements of air known as winds.

4. The velocity of a wind depends upon the difference in air pressure between two regions.

What are monsoons? In summer the weather in India and other parts of southern Asia is very hot. The air becomes heated, expands, and so becomes lighter; the cooler air from over the Indian Ocean forces this lighter air upward and so creates strong winds (Fig. 88) blowing from the ocean over the land, bringing with them a great amount of moisture. When these winds, the summer *monsoons*, reach the slopes of the Himalayas, they are cooled sufficiently to cause much of their water vapor to condense and fall as rain. So much rain falls that this part of India is one of the wettest regions in the world.

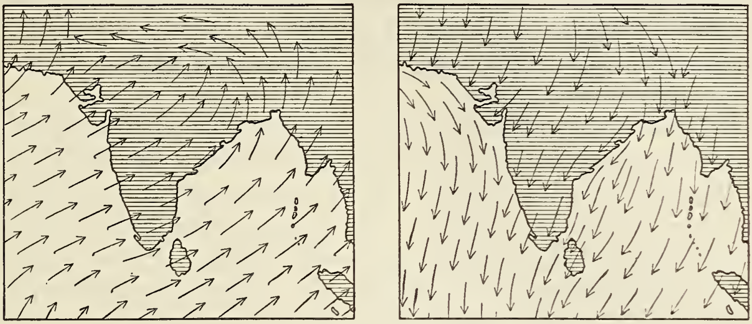


FIG. 88. Southern Asia, showing the monsoon region and the region of heavy rainfall. The arrows in the sketch at the left indicate the direction of the wind during July and August; those in the sketch at the right its direction during January and February.

In winter the land is cooler than the ocean, and the winds are reversed. Explain why. These winter monsoons coming from the high mountains are cool; as they blow toward the south they are warmed, thus increasing their capacity to hold moisture. Instead of causing rainfall, as do the summer monsoons, they bring with them a period of dry weather. Why?

All continents show some tendency toward the development of monsoons, but in India the monsoon blows so steadily and the change in direction comes so regularly that in early times sailing vessels went to India in summer and left in winter, in order to have fair winds both ways. Is the formation of summer and winter monsoons quite like that of sea and land breezes? Explain.

Wind systems of the earth. Even greater air movements than the monsoons are caused by differences in temperature between the warm tropics and the cooler regions north and south of them. These great wind systems affect all of the continents and all of the oceans as you will now see.

What are the doldrums? The imaginary line on the surface of the earth which marks the belt of greatest heat received from the sun is called the *heat equator.* At the heat equator, air is heated, expands, and becomes lighter. Consequently, it is forced upward by the cooler heavier air which moves toward the heat equator from the regions north and south of it. Where this lighter air is rising there is little wind because the air movement is vertical instead of horizontal. This region is known as the *doldrums,* or the equatorial *belt of calms.*

What are the trade winds? The air currents that move toward the equatorial belt of calms are *trade winds.* They blow with great steadiness, especially over the oceans. Instead of blowing directly from the north in the northern hemisphere and directly from the south in the southern hemisphere, the trade winds are deflected by the rotation of the earth, becoming northeast trade winds in the northern hemisphere and southeast trade winds in the southern.

What are the anti-trade winds? Some of the air that moves upward in the equatorial belt of calms flows northeast above the northeast trade winds, and some flows southeast above the southeast trade winds. These upper currents of air are known as the *anti-trade winds.* They are known to be real winds because they are felt on high mountains that reach above the level of the trade winds; sometimes clouds drifting along with these anti-trade winds may be seen moving in a direction opposite to that of the trade winds.

When the air of the anti-trade winds reaches the north and south limits of the trade winds, it descends to the earth. These belts of calm are known as the *horse latitudes.* Where air is falling there is little wind. Why? The horse latitudes lie between 30° and 35° north latitude and between 30° and 35° south latitude.

What are the prevailing westerlies? Part of the anti-trade winds that descend at the horse latitudes moves back toward the equator as trade winds; but a great quantity moves onward from the horse latitudes in the general direction of the poles. Instead of traveling directly north in the northern hemisphere and directly south in the southern hemisphere, these winds which are also deflected by the rotation of the earth move to the northeast in the northern hemisphere and to the southeast in the southern hemisphere. These winds are the *prevailing westerly winds* so common in temperate zones.

Thus the great winds—the trade winds, the anti-trade winds, and the prevailing westerlies—keep up a circulation of the atmosphere all over the earth and so distribute heat and moisture. These winds are temporarily interfered with by storms, sea breezes, elevations of the land over which they blow, and the like, but in general they are the prevailing winds of the earth.

What is a cyclone? A *cyclone* is a large storm area, sometimes a thousand miles in diameter, moving over the earth's surface. In addition to the onward movement of a cyclone, air currents are moving in a great whirl around a low pressure area which is the center of the storm. Figure 89 shows the direction of air currents in the center of a cyclone north of the equator. The cyclone is traveling east. If a person is ten miles east of the storm center, from what direction does the wind blow? From what direction does he feel the wind when he is near the center of the low?

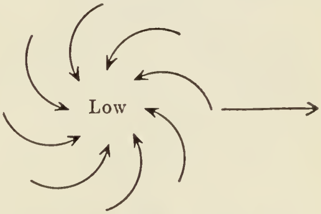


Fig. 89. A low, showing the direction of the winds near the center of a cyclonic storm.

Most storms that reach northern North America seem to originate in northern Pacific waters near the Aleutian Islands. After reaching the western part of the United States and Canada they usually move over the country in an easterly direction. Some cyclones appear to originate in the Rocky Mountain Plateau and others in the region around the West Indies. Sometimes a storm appearing in the vicinity of the West Indies moves northward along the eastern coast of the United States accompanied by rain or snow; or one of these storms may move across the Gulf of Mexico and enter the mainland in the vicinity of Texas or Louisiana and then proceed in a northeasterly direction over the central and eastern part of the United States. An interesting feature about all these cyclones is that, regardless of where they enter the United States, if they cross the country, they leave either by way of the St. Lawrence Valley or the northeastern corner of the United States. Occasionally storms from the Pacific pass southward along the Pacific coast, causing heavy rains in the western part of Washington, Oregon, and northern California.

The approach of a cyclone. As the center of a cyclonic storm approaches, the sky becomes cloudy and there is likely to be precipitation. The barometer falls. The atmospheric pressure at the center of a cyclonic area is lower than that of the surrounding regions and is marked low on the weather map. Air from all directions moves toward this low-pressure area.

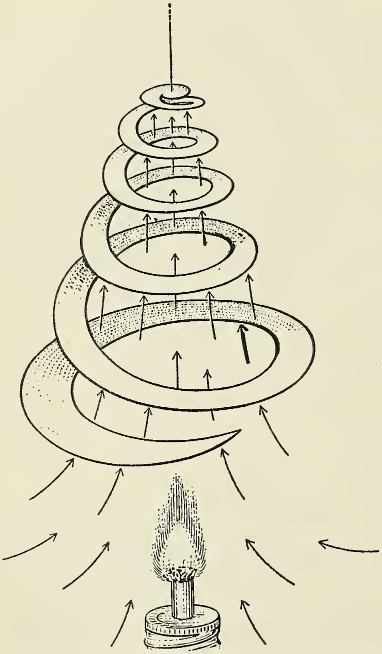


Fig. 90. What causes the air to rise? What causes the spiral to turn? In what direction is the air moving a short distance away from the flame?

Experiment 52. To show how warm air moves. Cut a piece of paper in the form of a spiral (Fig. 90) and hold it over a flame.

Likewise, in a cyclonic storm, winds blow toward the center from all directions. The velocity of these winds varies in different parts of the storm area, but the difference is never very great. Because of the deflection due to the rotation of the earth, the winds do not blow directly toward the center of the cyclone but in a curved direction (Fig. 89), producing a great whirl in which the air moves inward and then upward. These winds are deflected to the right in the northern hemisphere and to the left in the southern hemisphere; so that in the northern hemisphere the whirling movement is opposite to the hands of a clock (counter-clockwise) and in the southern hemisphere clockwise. As the air near the center of the cyclone moves upward, it is cooled, and precipitation usually occurs.

We are now ready to learn how a cyclone affects the weather. Suppose you live east of the Rocky Mountains. One of the first indications of a change in the weather will be a change in the direction of the wind. As the center of the cyclonic area moves from the west, the wind where you are will blow from the northeast or east, bringing moist air from the Atlantic Ocean. Very likely there will appear in the west, i.e., in the direction of the coming cyclone, thin sheets of thread-like or feathery cirrus clouds.

As the cyclone progresses eastward, the winds south of the storm center shift from the east to the southeast and south, bringing great quantities of moist, warm air from the direction of the Gulf of Mexico. As this warm, moist air approaches the center of the storm, it comes into a region of reduced pressure which causes the air to expand. Consequently, the air becomes cooler and the water vapor in it begins to condense. As the condensation continues, the sky becomes entirely covered by a dark gray rain cloud (nimbus). Then rain or snow begins to fall. People may refer to the rain, if it lasts for a day or two, as a "settled rain." If snow falls and the wind blows it through the air and piles it up in drifts, we call the storm a blizzard.

What is an anticyclone? As a cyclone passes eastward, the low pressure area moves with the prevailing westerlies toward the east or northeast. The wind begins to shift to the southwest and finally to the west. Now a high pressure area is approaching, referred to as an *anticyclone,* in which air currents are descending.

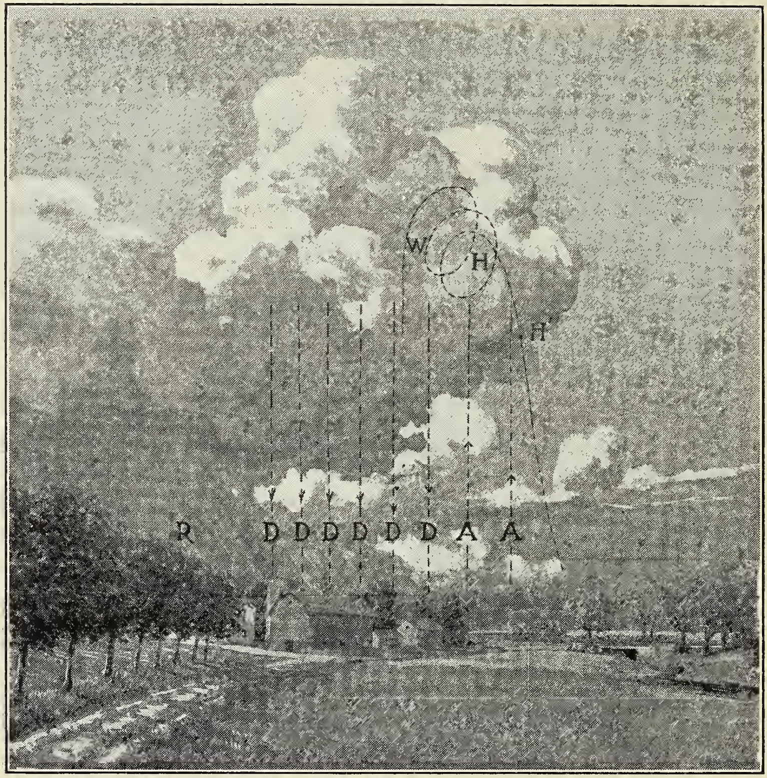
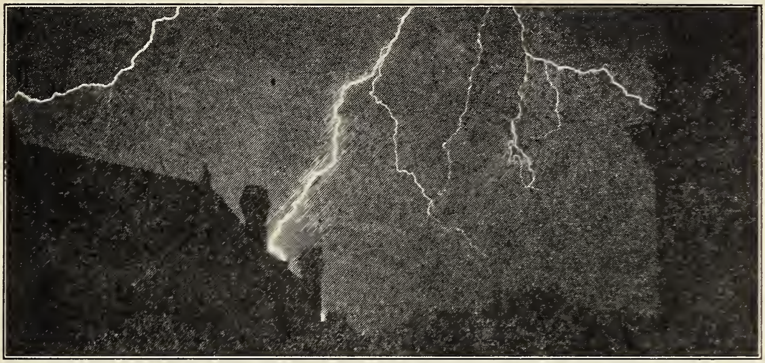


Fig. 91. How rain and hail are formed in a thunderstorm. *A* represents warm ascending air containing much water vapor; *D*, cold descending air containing little water vapor; *W*, a drop of water formed from condensed vapor; *H*, hail; *H′*, a hail stone; *R*, rain.

The air in these currents is cool and dry. It is cool because it comes from the upper layers of the atmosphere, and it is dry because in moving downward it is becoming warmer and consequently is increasing its capacity for holding moisture. The sky begins to clear. The dark nimbo-stratus cloud is "breaking up," that is, it is being absorbed by the drier air from the anticyclone.

As the cyclonic area passes eastward, with the wind shifting to the west, the sky is generally clear or partly clear until the approach of another cyclone.



Courtesy U. S. Weather Bureau

FIG. 92. Lightning flash photographed at Middletown, Maryland.

Thunderstorms. Thunderstorms occur frequently in equatorial regions and occasionally during the warm seasons in the temperate belts. They may occur in connection with cyclones or they may originate as local storms. The first indication of a thunderstorm is the appearance of cumulus clouds, usually in the west. They gradually increase in size and become darker and darker as the storm approaches. Such a storm usually moves forward at the rate of thirty or forty miles per hour. The observer frequently notices a great overhanging, fan-like front (Fig. 91), miles in length. A severe thunderstorm is usually characterized by a squall, heavy rain, and lightning. Sometimes it is accompanied by high temperature and high relative humidity.

The electrical display of thunderstorms has been a matter of interest, if not of terror, since the dawn of history. The lightning flash (Fig. 92) is a phenomenon discussed more fully on page 432.

People caught in an electric storm are safer in a valley than on a ridge. It is unwise to take shelter beneath a solitary tree in a thunderstorm because lightning is likely to strike tall objects like trees and church steeples.

Sometimes lightning rods are placed on buildings and on valuable trees to protect them from the destructive effects of electrical storms. If properly installed a lightning rod is a great protection to property (page 432).

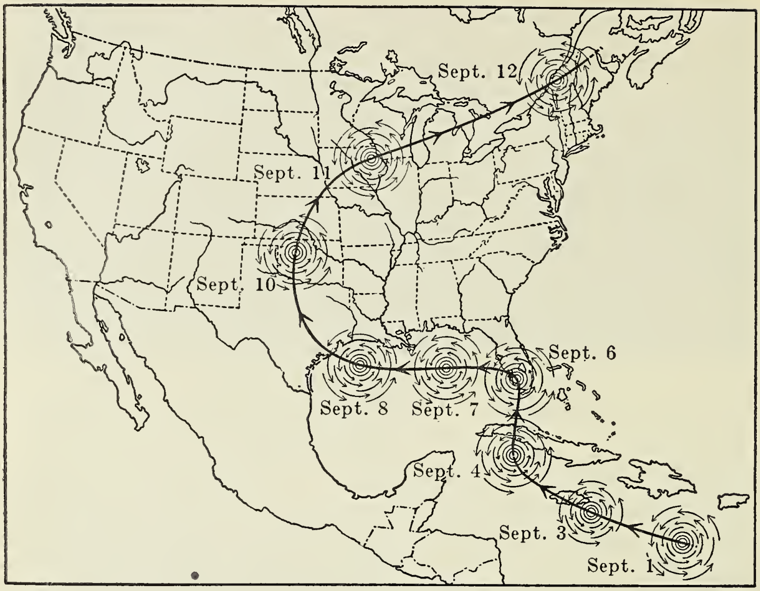


FIG. 93. The path of the Galveston hurricane, 1900. After the hurricane left Galveston, it decreased in violence, because it had already expended part of its force.

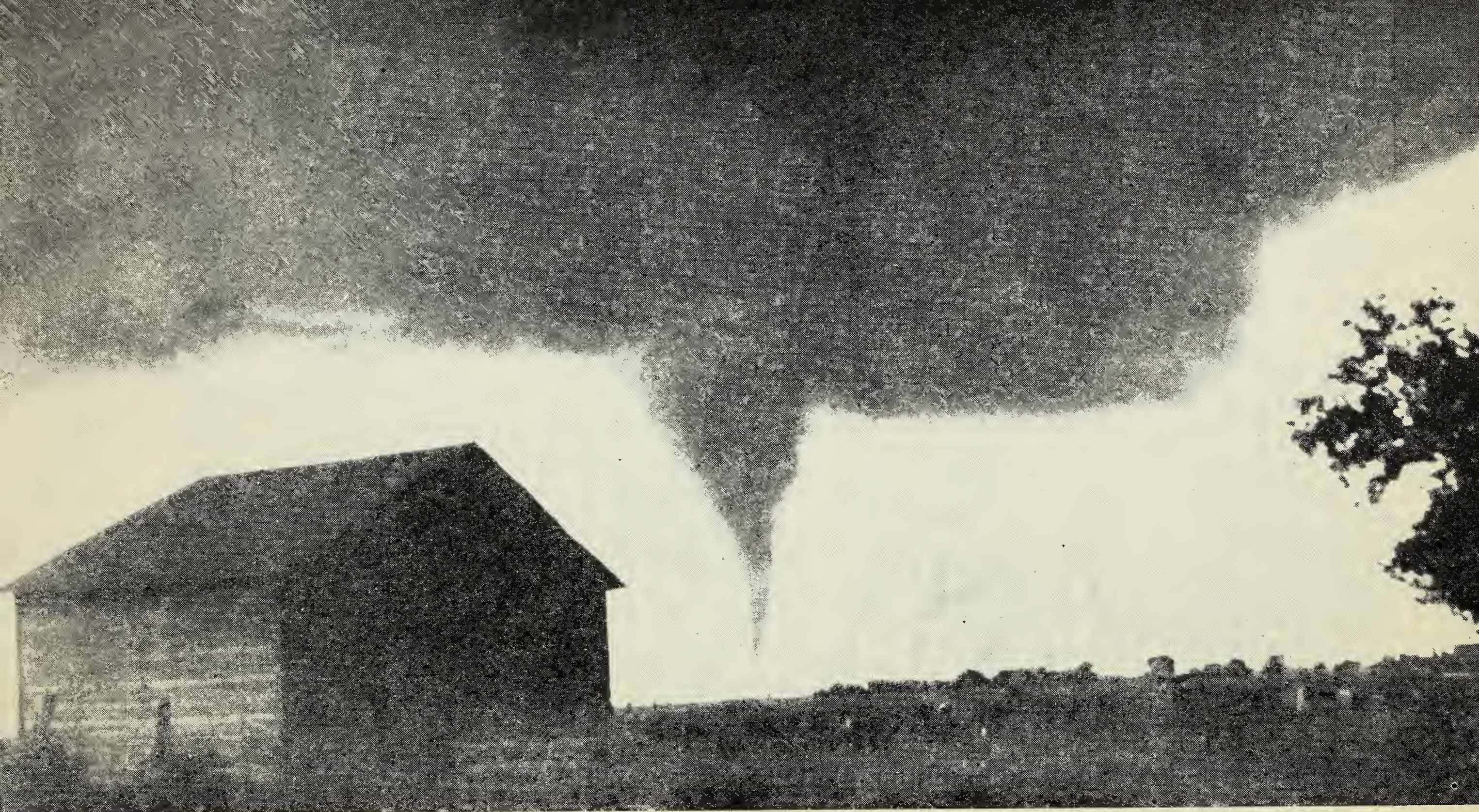
What is a hurricane? Storms similar to cyclones, though much more violent, occur over tropical waters. Around the West Indies they are called *hurricanes;* off the coast of Asia, *typhoons;* and in the Indian ocean, *cyclones.* These storms, which originate in the regions of calm near the equator, take a long sweeping course westward and then turn toward the poles. Sometimes they enter the temperate belts, where they either disappear or continue as rather violent cyclones over the land. The hurricane which destroyed a large part of Galveston in 1900 proceeded across the country as a cyclone, leaving by the way of the St. Lawrence Valley (Fig. 93). The great hurricane of 1926 which devastated Miami, Florida, and adjacent territory, and also the one in 1928 which destroyed nearly all the crops and many buildings in Puerto Rico, had all the destructive effects of a very large tornado.

What is a tornado? A *tornado* is a storm small in extent and generally occurring in the southeastern part of a cyclonic area. Several tornadoes may develop at the same time a short distance from one another. They are most prevalent in the Mississippi Valley. A tornado travels in a narrow path varying from a few rods to a half mile in width, and moves with a speed of from twenty-five to thirty-five miles per hour. In addition the air whirls or rotates very rapidly. This is why it is called a "twister." The speed of the whirling wind in tornadoes is estimated to be as high as five hundred miles per hour. The appearance of a tornado is that of a funnel-shaped cloud, serpent-like, or similar to the shape of an elephant's trunk (Fig. 94). Its approach is accompanied by a loud roaring and a rumbling noise. Some of the effects of tornadoes, such as driving straws through boards, plucking feathers from live chickens, and twisting off tree trunks as we would break off stalks of celery, seem almost incredible.

A tornado at sea causes a *waterspout*. One near the coast of India, measured from the British steamer, War Hermit, was 4600 feet from the surface of the water to the base of the overlying cloud. The column of water tapered from a width of 500 feet at the cloud to 150 feet at the sea. Spray at the base of the column was thrown up several hundred feet.

PROBLEM: HOW DOES OUR SCIENTIFIC KNOWLEDGE OF ATMOSPHERIC CONDITIONS ENABLE US TO FORECAST CHANGES IN THE WEATHER?

Weather forecasting. In the United States weather forecasting is one of the duties of the Weather Bureau in the Department of Agriculture. In the Bureau there are five stations known as forecast centers: Washington, New Orleans, Chicago, Denver, and San Francisco. In addition to these there are about 200 stations with full-time weather men in charge and more than 5,000 stations maintained by unpaid volunteers. These stations are located in different parts of United States, Canada, Mexico, Alaska, and West Indies. At 8 a.m. and 8 p.m. each day about 300 of these stations report by telegraph to the forecast centers.



Courtesy U. S. Weather Bureau

Fig. 94. Tornado photographed at Hardtner, Kansas.

These reports are assembled and are sent by telegraph to some sixty map-making and forecasting stations. Each report gives information regarding temperature, barometer reading and trend during the past three hours, precipitation, direction of wind, state of weather, current wind velocity, clouds, maximum and minimum temperatures since last report. From these reports weather maps are compiled and forecasts are made. Weather reports are printed in newspapers and bulletins and broadcast over radio. Weather maps (Fig. 95) are printed in newspapers, in bulletins, and elsewhere.

The solid lines on the maps, called *isobars*, are drawn through places having the same atmospheric pressure. The dotted lines, called *isotherms*, are drawn through places having the same temperature. The arrows in a continuous line indicate the path of winds as they move across the country.

Shaded areas show regions where .01 inch or more of rain, snow, or sleet fell during the preceding twenty-four hours. If the circle on an arrow is clear, a clear sky is indicated. A circle half shaded means a partly cloudy sky. A circle entirely shaded indicates that the whole sky is cloudy.

The arrows on those circles indicate the direction of the wind at a particular locality. The letters, "R," "S," and "M," indicate respectively "rain," "snow," and "report missing." "F" indicates "fog"; ▲ hail; △ sleet; —◒→ storm warning; "CW" cold wave warning; —⊕→ storm track and location of storm center. Barometer readings are expressed as if they were at sea level. The places marked "Low" are centers of cyclonic storms. Places marked "High" are anticyclonic areas.

The accompanying map shows a storm which traveled from Vancouver southward, cut across the Gulf of Mexico and then traveled up the eastern coast of the United States to Nantucket and farther out to sea. Two days before the storm struck Nantucket, the United States Weather Bureau there reported the lowest pressure on record for more than sixty years since the establishment of the bureau—28.44 inches. Where is the lowest barometric pressure recorded during the progress of the storm (Fig. 95)?

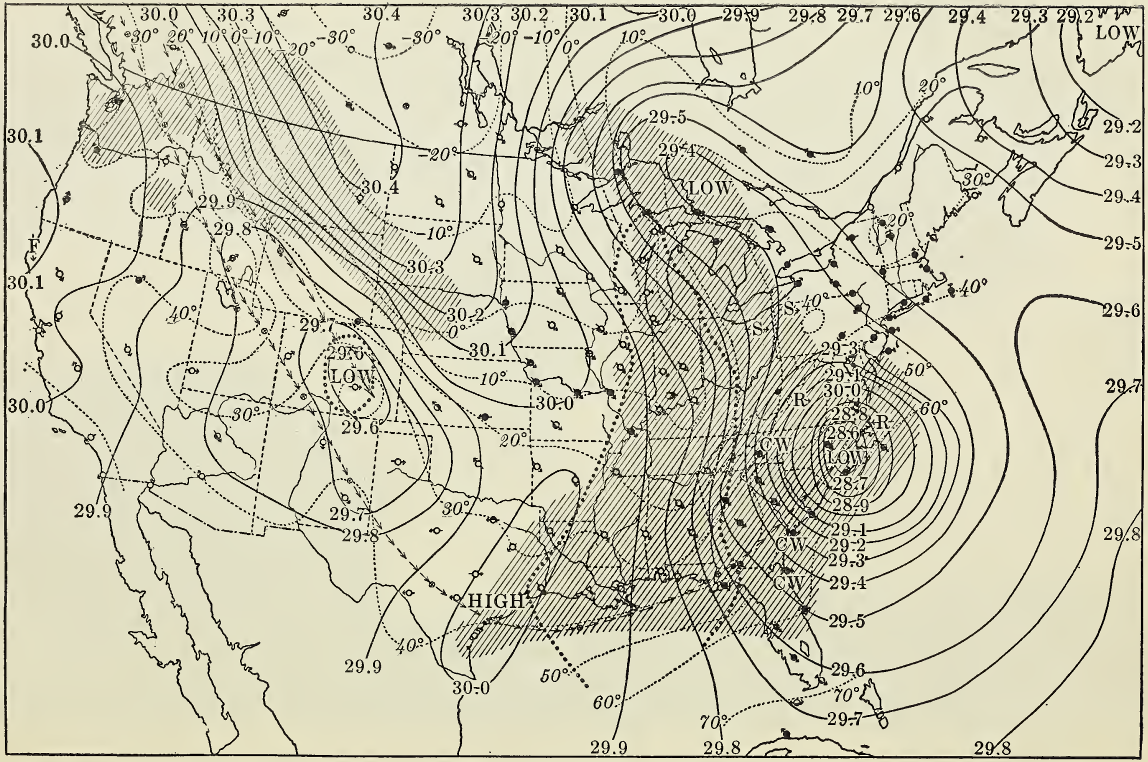


FIG. 95. A simplified weather map. Find the approximate location of your home and answer the following questions for the day the map was made: What was the atmospheric pressure there? the temperature? Which way was the wind blowing? Was there precipitation?

Weather services similar to that of the United States are maintained by the Canadian and Mexican Governments and observations are received daily from these countries.

Daily observations are also received from Iceland, Greenland, Great Britain, nearly all the countries of Europe, China, Japan, and ships at sea. Exchange of weather information is an example of cooperation between peoples of many nations.

Special problem. Have your teacher procure from the nearest office of the United States Weather Bureau a series of four or five weather maps for successive days. Select maps the first of which shows a storm area (a "low") near northern Texas, or in the vicinity of Montana, or along the northern part of the Pacific Coast. Trace on the maps for the succeeding days the progress of one of these "lows" as it moved over the country. Write a short report describing the progress of the storm and its effects on the general weather conditions in the section of the country through which the "low" passed. Some of the weather conditions to note are: Atmospheric pressure, direction of wind, appearance of sky, precipitation, and temperature changes.

Special report. When a "low" seems to be approaching the section of the country in which you live, you can report on your own locality, noting the changes in weather conditions before and after the storm passes.

About 85 per cent of the weather forecasts are accurate. Forecasting is based largely upon observations concerning the approach of cyclones. From his knowledge of weather conditions in the past and from his current observations, the weatherman attempts to forecast the state of the weather for about thirty-six hours in advance. Of course, his forecasts are not always borne out as cyclones frequently change their direction or disappear entirely.

Making observations in the upper atmosphere. More and more, knowledge of conditions in the upper atmosphere is becoming important for purposes of general weather forecasting and for furnishing information to aviators. Upper atmosphere observations were first made by sending up kites to which recording instruments were attached. Later a pilot in an airplane was sent up with instruments. Now a free balloon is sent up to which are attached automatic recording instruments. As the balloon rises these instruments send out a continuous wireless report which is recorded at the station. The balloon rises until it bursts. Then the instruments which are attached to a parachute fall harmlessly to the ground.

Who makes use of weather forecasts and warnings. At more than 400 points along the Atlantic, Pacific, and Gulf Coasts, and the shores of the Great Lakes storm warnings are displayed from 12 to 24 hours in advance of a storm. The time at which vessels engaged in ocean or lake traffic will sail is largely determined by these warnings and other information furnished in forecasts. Fishermen are also guided by forecasts and warnings as to when they will return or leave port. If a storm is approaching, they take steps to protect their boats and nets.

The warnings of a cold wave or frost enable fruit growers to protect their orchards by smudges; truck growers to protect their gardens with blankets, paper or straw; railway and other transportation companies to protect perishable goods against freezing in shipment. With warnings of an approaching cold wave, doors and windows of greenhouses are closed and boilers are fired. Fire plugs and exposed water pipes are protected; automobile water-cooling systems are protected by putting anti-freeze into them; gas companies turn a larger amount of gas into the mains; fruit and vegetables are picked or protected; and if a severe cold wave is approaching, livestock is brought into barns and sheds from the range.

Forecasts of rain guide farmers as to when to harvest oats, wheat, hay, and other crops which are damaged by rain after they have been cut. Weather forecasts also may influence you as to whether or not you will wear your rubbers and take your umbrella to school. If you are planning a long trip, you may be able to take a route that will avoid the storms.

A knowledge of weather conditions is indispensable to aviators. It allows them to fly around or over storm centers. If they think weather conditions are too unfavorable, they need not fly. Airline companies receive weather reports every hour, or more frequently, if changes in the weather are taking place rapidly. Many people make use of weather reports.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

anticyclone
antitrade winds
cirrus
cloud
cumulus
cyclone
dew point
doldrums
fog
forecasting
frost
heat equator
horse latitudes
humidity
hurricane
isobar
isotherm
monsoons
nimbo-stratus
precipitation
prevailing westerlies
rain gauge
relative humidity
sleet
stratus
thunderstorm
tornado
trade winds
typhoon
waterspout

Write the number of each item on your paper and after it the word that completes the statement.

1. Cyclones are areas of __________ barometric pressure.

2. Anticyclones are areas of __________ barometric pressure.

3. Differences in atmospheric pressure produce currents of air called __________.

4. On a weather map localities having equal air pressure are connected by a line called an __________.

5. A line on a weather map connecting places having the same temperature is called an __________.

6. A cyclonic storm center is indicated as a __________ on a weather map.

7. Warm air has a __________ capacity for water vapor than cold air.

Which item in each of the following lists does not belong with the others?

8. cloud; cumulus; cirrus; nimbo-stratus; rain gauge.

9. isobar; isotherm; climate; temperature; pressure.

10. stratus; trade wind; monsoons; typhoon; antitrade wind.

Which of these statements are true? If any are false, re-state them in correct form.

11. A given volume of cold air is lighter than an equal volume of warm air.

12. In general, cyclonic storms sweep across the United States from east to west.

13. Tornadoes are great whirling masses of air several miles in diameter.

14. The amount of water vapor in the air is known as temperature.

15. The statement that dew "falls" is true.

THOUGHT EXERCISES FOR UNIT IV

Principles of Science

Make a list of the principles of science in this unit. One of them is: Winds blow from a region of higher air pressure to one of lower.

Questions or Problems

1. Name five industries that depend chiefly upon weather conditions.
2. Does moisture in air make it heavier? Explain.
3. From the standpoint of science is it correct to say that snow is frozen rain?
4. Give two reasons why railroad operators are interested in the weather.
5. What becomes of fog as it disappears?
6. Cities along the southern shore of Lake Erie frequently have lower temperatures in spring and higher temperatures in autumn than cities several miles south. Explain.
7. Why is it dangerous to be under a tree during a severe thunderstorm?
8. Why does a falling barometer indicate the approach of a storm?
9. A small hydrogen balloon, when released at a government proving ground, started to float toward the west, but after rising to a considerable height, it turned and drifted toward the east. Explain.

Projects and Reports

1. For a period of two weeks, cut out the official weather forecast from a daily newspaper. Paste each one neatly in your notebook. Check each forecast to show whether it agreed with actual weather conditions.
2. For a period of two weeks keep a daily weather record. Each day enter the following items: Date, barometer reading, temperature (Fahrenheit), weather conditions, appearance of sky (cloudy, clear, etc.), direction of wind, and strength of wind.
3. If there is an airport in your locality, visit it and make a report on "How Weather Conditions Affect Flying."
4. Make a list of occupations, sports, and business conditions that are affected to a large extent by weather conditions.
5. If you live near a large body of water, find out where storm warnings are displayed, why they are displayed, what the storm warnings mean, and who displays them.

6. Find out whether daily weather reports for your community are sent to the United States Weather Bureau, Washington, D. C., each day. Find out who makes and sends them, and describe fully the weather report.

7. Get a series of daily weather maps for a period during which a storm swept across the United States. Trace the path of the storm. Note the changing weather conditions for the different cities and states affected as the storm moved across the country.

8. With the aid of your daily newspaper or daily weather maps, record the average temperature and atmospheric pressure for two weeks. Plot your data and draw the graph. Explain from your results any weather conditions they may indicate.

9. Draw two graphs according to the instructions given below:
   (*a*) Plot the data that represent changes in temperature from hour to hour for either 12 or 24 hours. Show changes in temperature on the vertical axis; and units of time (hours) on the horizontal axis.
   (*b*) Plot data representing changes in air pressure (barometer readings) from hour to hour for 12 consecutive hours. Show changes in barometer readings on the vertical axis; and units of time (hours) on the horizontal axis.

When the graphs are completed explain them to your class.

10. Make a daily study of clouds and their forms for two weeks. If you can, determine the relation of each form to the weather.

11. Make a rain gauge and compare its readings with those reported by the local weather bureau.

REFERENCES FOR READING AND STUDY

1. Brooks, C. F., *Why the Weather?* Harcourt, Brace & Company.
2. Elm, I. E., *Weather and Why.* David McKay Company.
3. Free, E. E., and Hoke, Francis, *Weather.* Robert McBride & Company.
4. Humphries, W. J., *Fogs and Clouds.* Williams and Wilkins.
5. Kendrew, Wilfred G., *Climate.* Clarenden Press, Oxford.
6. Moore, Willis Luther. *The New Air World,* Chapters VI, VII, IX, XVI. Little, Brown & Company.
7. Talman, C. F., *The Realm of the Air.* Bobbs Merrill Company.
8. Van Cleef, Eugene, *The Story of the Weather.* D. Appleton-Century Company.

UNIT V

WHAT IS THE UNIVERSE AND WHAT IS THE PLACE OF OUR EARTH IN IT?

Exploring the Heavens

For ages the shepherd guarding his flocks, the leader of a caravan traveling across the desert, and the sailor piloting his ship across the sea were guided by the stars and particularly by one, the North Star. They observed with wonder and admiration the changing moon and many groups of stars. To some of these groups of stars they gave names and likewise to the planets Mercury, Venus, Mars, Jupiter and Saturn. These names have come down from antiquity.

Even in the early days of your grandparents people traveled through the country at night by the light of the moon and the stars. During winter nights they consulted an almanac to find out the phases of the moon and to learn as they thought whether the coming season would be dry and hot or wet and cold.

But why do we study the heavenly bodies today? We live near bright lights or carry them with us. At night automobiles are guided by lighted signs and airplanes by beacons.

Men today observe and study the heavenly bodies to satisfy the same curiosity that urges the scientist to study the earth, the depths of the sea, and the stratosphere. He knows now that the earth is not the center of the universe but one of at least nine planets revolving around the sun, the source of all life and energy. The sun, the planets with their moons, smaller bodies, called planetoids, and mysterious bodies with tails, called comets, all these together make up the great solar (sun) system. Astronomers' observations have lead them to conclude that each of the millions of stars is the center of a solar system. All these solar systems taken together make up our universe, furthermore our universe is just one of many others.

CHAPTER XI

HOW IS THE EARTH RELATED TO THE SUN AND THE OTHER STARS?

Do you know:

That all the energy on the earth comes from the sun? That in ancient times the sun was worshipped as a god? That the sun is losing weight? How scientists can tell what the sun is made of even though it is 93 million miles away?

How many planets there are? Which is the largest planet? What new planet was discovered in 1930? Why the moon changes from "new" to "old"? That the moon causes the tides?

That when you look at a certain bright star, the light that enters your eye from it left that star before your grandfather was born? How to tell direction from the North Star? How a comet differs from a meteor?

Problem: Does the Sun Furnish All the Energy Used on the Earth?

Stop for a moment and picture the world without the sun. Without sunlight plants would die; animals would starve; and soon all life would cease. Without heat from the sun the earth would be unbearably cold. The only light on the earth would be the faint light from stars. Even the mellow light from the moon would no longer fall on the earth, for the light of the moon is light reflected from the sun.

But, you say, we could still use electric lights; we could still heat our homes with coal; we could raise plants in artificial light. But could we? As you study this chapter you will learn that life depends on the sun—directly or indirectly.

The sun-god of the ancients. The Greeks understood what an uncomfortable place the world would be without the sun. Hence, they worshipped the sun as a god. When they saw the first faint coloring of rose and gold in the eastern sky at break of day, they said, "The sun-god has mounted his chariot and is starting out on his daily course across the sky." When they saw the fiery ball of the sun sinking in the west, they thought that the god and his chariot were disappearing into the ocean, to travel under the earth during the night to arrive in the east again at the dawn of a new day.

Of course, we know better than this today. We know that it is the rotation of the earth on its axis that causes day and night and the apparent movement of the sun.

✓ **Experiment 53. To compare the size of circles representing the sun and the earth.** Place the top of a large sheet of paper even with the bottom line of Figure 96. With a compass complete the circle which represents the circumference of the sun. Compare the size of this circle with the black dot representing the earth.

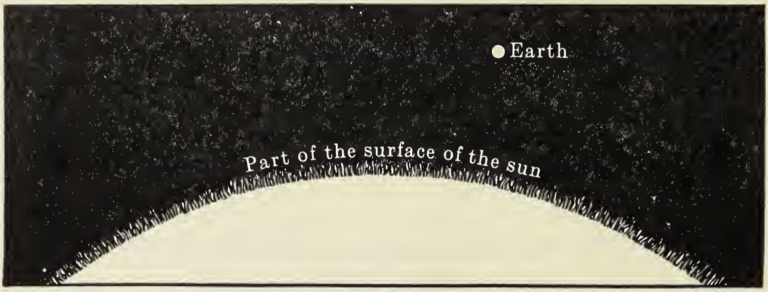


FIG. 96. Part of the surface of the sun compared with the surface of the earth.

How large is the sun? The ancients probably had little idea of the size and composition of the sun. Careful calculations lead modern scientists to believe that the diameter of the sun is about 865,000 miles, more than 100 times the diameter of the earth. The vastness of the sun can be more fully realized, however, by comparing the volumes of the sun and the earth. It can be shown by geometry that the volume of the sun is more than one million times that of the earth; that is, the sun would make more than a million bodies the size of the earth.

What is the sun made of? The sun is a great, fiery-hot mass of material with an atmosphere composed of a mixture of gases. At the temperature of the sun, many substances which in their natural state on the earth are solids, are in a gaseous state. The atmosphere of the sun contains many elements found on the earth, such as copper, carbon, calcium, iron, lead, nickel, oxygen, potassium, sodium, tin, and zinc. Remember that on the sun all of these are in a gaseous form. The following experiment will help you to understand how scientists have determined that the sun is composed of these and other elements.

Experiment 54. To show that the color of a flame is caused by highly heated substances. (a) Light a Bunsen burner and adjust the volume of air admitted until a clear blue flame is secured. Using a pair of pliers, hold a piece of copper in the flame. The heat causes a small amount of the copper to vaporize. Withdraw the copper and again insert it into the flame. What is the color of the copper vapor? Continue to do this until you are convinced that the color of the flame is caused by the copper vapor. What is the effect of the copper vapor on the color of the flame?

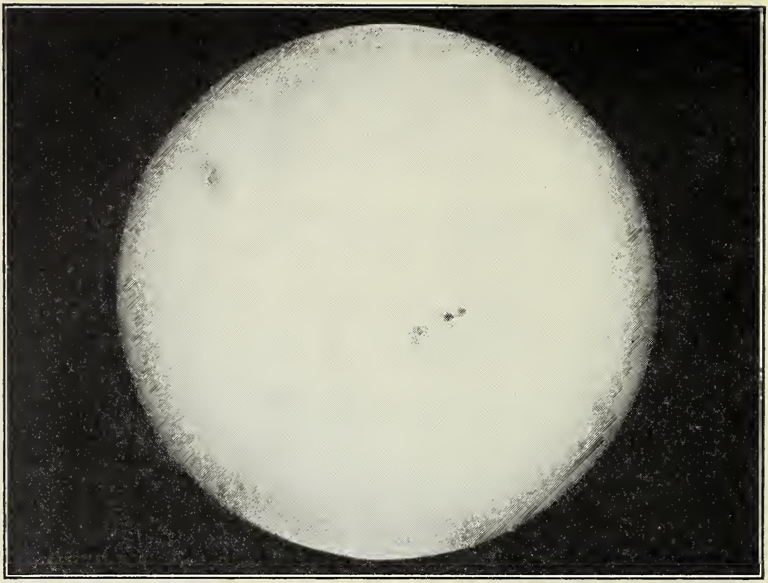
(b) Place a small quantity of salt in the flame and observe the color. What is it? This color is due to the sodium in the salt, which vaporizes in the flame.

When any element is heated to *incandescence* (hot enough to glow) it shows a characteristic color. The characteristic color for copper is green. What is the characteristic color for sodium?

What is a spectroscope and how is it used? When white light passes through a glass prism, it is spread out into a band of colors, called a *spectrum.* A spectrum can also be seen by looking through a prism at a beam of light. A *spectroscope* is an instrument in which a prism is placed in such a way that you can look through it at a light and see its spectrum.

The spectrum of a candle flame is a continuous band of color ranging from red to violet. If a little salt is placed in the flame, as in Experiment 54, the flame is filled with sodium vapor and a yellow-orange light is emitted. The spectrum of this light usually appears as a single bright yellow line. The spectrum of each element is different from that of every other element; consequently we can identify an element by its spectrum.

The spectrum of sunlight. You would probably expect that the spectrum of sunlight would be a continuous band of colors as



Courtesy U. S. Naval Observatory

Fig. 97. The spots on the sun shown here were really one spot which was more than 100,000 miles long. Sun spots are caused by great eruptions on the sun, which hurl highly heated gases far out into space.

is the spectrum of a candle flame. However, in the spectrum of sunlight there are dark lines. A study of this problem showed that if light from any source was passed through the vapor of an element, the spectrum of the light would show dark lines corresponding to the bright lines in the spectrum of the element. For example, if light from a candle passes through sodium vapor the spectrum of the light will not be seen as a continuous band of color, because it will show a dark line which corresponds to the bright yellow line sodium usually shows. Careful experiments proved that heated vapors or gases absorb the same kind of light they emit; hence a dark line in the spectrum of a light means that the light must have passed through the vapor of an element which absorbed that particular part of the light.

The elements that make up the sun's atmosphere, then, can be determined by means of a spectroscope. For example, if there is found in the sun's spectrum a dark line corresponding to the spectrum of sodium, sodium vapor must be present in the sun's atmosphere.

By studying the spectrum of sunlight scientists have determined the elements which make up the sun's atmosphere. Gold, mercury, arsenic, phosphorus, and other elements have not yet been found in the sun, but it would not surprise scientists if these elements were in its interior. Possibly at some future time one of the great bursts of flame that occur on the sun (Fig. 97) will bring these elements in a highly heated gaseous state to the surface of the sun. If so, astronomers will then be able to identify them with the aid of the spectroscope.

How the element helium was found. The discovery of the element helium shows how scientific knowledge was advanced by the use of the spectroscope. A French astronomer, Janssen, traveled to India to observe the total eclipse of the sun on August 18, 1868. The spectroscope was just beginning to be used to determine the composition of highly heated gaseous substances. During the short period of the total eclipse, Janssen directed the spectroscope upon the highly heated gases that shoot out millions of miles from the sun's surface. When an eclipse shuts off light from the sun, these shooting columns of highly heated gases can be seen and studied. As Janssen studied the spectrum of these gases he noted a line that he had not seen before. Later as he directed the spectroscope during bright sunlight upon the edge of the sun, he was surprised to find the same line that he had discovered during the eclipse. He then knew that he could study this new line in the solar spectrum whenever there was sunlight. Further study convinced him that the new line in the solar spectrum was not caused by any element already known on the earth, but by a new element. Other scientists confirmed his work and this new element, which had not yet been discovered on the earth, was called helium (from the Greek word *Helios* meaning "sun").

Further study with the spectroscope showed this new element to be a part of certain stars in the constellation of Orion. Years passed, however, before any trace of this element was found on the earth. In 1894, about twenty-five years later, Sir William Ramsay and Lord Rayleigh reported that they had found this bright line of helium in the spectrum of gases given off by a substance known as Norwegian cleveite. Careful studies and comparisons of this line in the spectrum of cleveite and the line found by Janssen in the solar spectrum in 1868 proved that these two lines were identical, and consequently that the element in cleveite was the helium already found in the sun. Shortly after this Dr. Ramsay and Lord Rayleigh found a very small quantity of helium in the earth's atmosphere. In more recent times it was discovered in some of the natural gas produced in southern Kansas, Oklahoma and Texas, and from this source the helium now used for inflating balloons is obtained.

Today we know helium as a colorless, odorless, tasteless, and non-inflammable gas; lighter than any other element except hydrogen. It is used to inflate balloons and airships. Why?

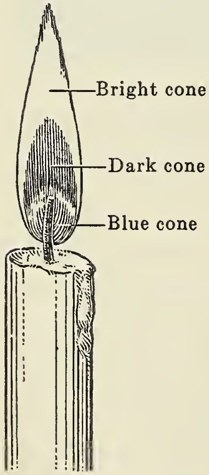
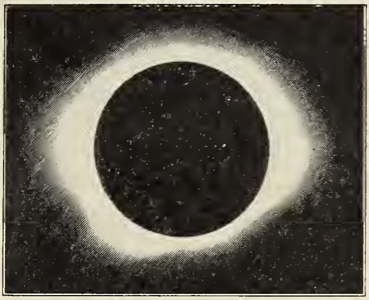


Fig. 98. The three cones in a candle flame.

What are the three layers of the sun's atmosphere? Scientists have discovered that the sun's atmosphere is made up of three layers. The following experiment will help you to understand how these layers differ.

✓ **Experiment 55. To show the three layers of a candle flame.** Light a candle and observe carefully the three different cone-like shapes which appear in the flame (Fig. 98). They are really cone-like bodies of gas at different temperatures. Describe the appearance of each of the three cones.

The layers of the sun's atmosphere may be compared to the layers of the flame of a candle. The sun is composed of a central core surrounded by three layers of heated gases. The core of the sun is believed to be about as thick as molasses. Around this core is a dark layer of flame, called the *photosphere*, which corresponds to the inner cone of the candle flame. Around the photosphere is a layer about 5000 miles thick known as the *chromosphere* from which great flames shoot out into space for vast distances. To what cone in the candle flame does this layer compare? On the outside is a thin layer, the *corona*, which can be seen only at the time of a total eclipse of the sun (Fig. 99).



Courtesy University of Michigan

FIG. 99. The corona of 1932.

What are sun spots? We cannot even begin to imagine what a tremendous fiery furnace these three layers are. The core of the sun is like a gigantic power plant sending out leaping pillars of flame in every direction. The whole surface is a vast heaving, whirling mass of flames and burning gases. Everywhere the surface is in violent agitation and eruption. From the sun enormous tongues of flame are thrown out into space for 300,000 to 400,000 miles. At times, huge mountains of burning gases and flames shoot out as violent eruptions from the interior of the sun.

It is thought that these violent eruptions form the dark spots on the surface called *sun spots.* Through a telescope these sun spots appear to be holes somewhat like the craters of volcanoes. When changes in the sun spots more violent than ordinary take place, magnetic storms frequently occur on the earth. These storms affect telegraph instruments, telephones, radios, and other electric equipment. At such times, too, the northern lights are often extraordinarily brilliant. Unusual conditions of rain and drought are also thought by some to be connected with changes in sun spots.

Does the sun rotate? The sun spots move steadily across the face of the sun in such a way as to leave no doubt that their motion is due to a rotation of the sun. By observing sun spots, scientists have found that the sun rotates at its equator once in about twenty-five days. The region on each side some distance from the equator lags behind, as much as two and a half days, and nearer the poles considerably more.

The brightness of the sun. The highly heated gases and flames of the sun produce a light (sunlight) many times brighter than any light that has yet been produced on the earth. The brightness of light on any surface is measured in *foot candles*. A brightness of one foot candle is the brightness of the light on a surface placed one foot away from a burning standard candle, i.e., a candle made from sperm (whale oil) and burning at the rate of 120 grains per hour. Light from the sun measured in foot candles is 823 followed by twenty-five ciphers.

One of the brightest known artificial lights is the light given off by an electric arc, but the light of the sun falling on an open area of the earth's surface on a clear day, though the sun is about 93,000,000 miles away, is nearly four times as bright as the light of the brightest part of the electric arc upon a surface one foot away.

What is the temperature of the sun? So far, scientists have not been able to measure the temperature of its surface accurately. They have estimated it, however, at from 6000° C. to 12,000° C. Sir James Jeans, the noted English astronomer, has estimated that the temperature of the interior of the sun is 40,000° C., and near the center perhaps 40,000,000° C. At present, scientists do not know what causes the extremely high temperatures of the sun.

As the sun is at such a high temperature, it is giving off energy rapidly. Observations indicate that it is giving off energy so rapidly that it is losing weight at the rate of 250 million tons per minute. This fact does not need to give us serious concern, for scientists tell us that the sun has been giving off energy at the same rate for millions of years and will continue to do so for millions more. Some of the world's greatest scientists are studying the problem of the sun's temperature and its loss of energy. The findings of these scientists do not all agree, but continued study will reveal more facts, thereby leading to more accurate conclusions concerning the nature and behavior of this heavenly body upon which our welfare depends.

How much energy (heat and light) does the earth receive from the sun? You have just learned that the sun is giving off energy at such a rate that it is decreasing in weight 250 million tons every minute. The earth receives only a very small part of all the energy. Why? But when you realize how much this really is, you will be astonished. It is estimated that every minute one square yard of the earth's surface upon which the sun's rays fall vertically receives enough energy to keep six 60-watt lamps in continuous operation for one minute. In other words in one hour enough energy would fall upon one square yard of surface to keep three hundred and sixty 60-watt lamps in continuous operation for one minute. From these facts you can readily see that if the sunlight which falls upon the roof of a house could be used directly, there would be an abundance of energy for doing all the work in the home. Man has not yet found a practical way of using directly the tremendous energy of sunlight; however, nature changes this energy by the evaporation of water and by growing plants into energy which man can and does use. Thus, directly and indirectly, all the energy we use comes from the sun.

How is energy from the sun used on the earth? Have you ever thought that energy from the sun makes possible your food, clothing, and shelter; runs the family automobile, as well as street cars, railroad trains, and ships; turns the wheels of industry; and does the rest of our everyday work?

You may say that the sun furnishes us only with light and heat. But it is the sun's energy which we know as light and heat that causes water to evaporate and also the movements of air called winds. Evaporation and winds bring rain to the earth, making all plant life possible. Growing plants store up energy from the sun in the form of plant food. All lower animals live directly or indirectly upon plants and thus use the sun's energy for life and movement. Man lives upon plants and animals and thus he too is dependent on the sun for life and movement.

In past ages plant life grew luxuriantly. These plants, with their store of energy from the sun, were buried in the earth and were changed to coal, gas, and oil. Today this energy, released from these substances by combustion, is used to light and heat our homes and office buildings and to turn the wheels of our manufacturing plants, of our automobiles, and of our other means of transporation.

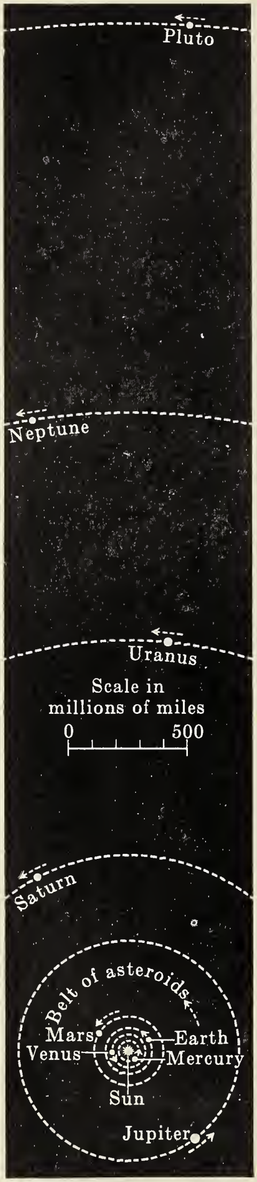


FIG. 100. The planets.

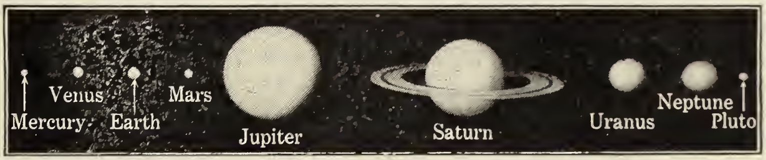
Your further study of science will give you even greater knowledge about the energy from the sun. It will reveal how some of this energy was stored up in the earth ages ago and how it is liberated today to make life possible and to do the work of the world.

PROBLEM: WHAT ARE THE NEAR NEIGHBORS OF THE EARTH AND WHAT ARE THEIR MOVEMENTS?

The vault of heaven. On a clear night the heavens appear to be an immense bowl turned upside down. It seems to an observer as if he were standing at the center of a huge, hollow, black hemisphere whose surface is dotted with planets and stars. The other half of the heavens might be thought of as a second bowl fitting over the other half of the earth.

What are the planets? Some of the most beautiful heavenly bodies are the *planets.* They were given the name "planets," from the Greek word meaning, "wanderer," because they seem to move, or wander, among the stars. In reality each planet revolves about the sun in a fixed path called its *orbit.* The planets are too cold to give off light of their own; we are able to see them because they reflect part of the light which they receive from the sun. They are not nearly so large as the stars, but some of them appear larger and brighter because they are so much nearer to us. Beginning with the one nearest the sun (Fig. 100) name the planets in the order of their distances from the sun.

What do scientists learn from the fixed markings on planets? In studying certain of the planets, astronomers have observed distinct fixed markings on their surfaces. If one of these planets rotates, of course its fixed markings move with the planet. By observing the time it takes these markings to return to any position a second time, astronomers are able to tell the time required for rotation, that is, the length of day on that planet. The planets Mars, Jupiter, and Saturn have very distinct markings; consequently, the length of day on each of these planets is known very accurately. Owing to the absence of fixed markings on Mercury, Venus, and Pluto, astronomers are unable to agree on the length of day on each of these planets. Some astronomers believe that Mercury and Venus keep the same hemisphere toward the sun at all times; if this is true, it is always night on one hemisphere of these planets and always day on the other hemisphere. Other scientists believe that these two planets rotate very rapidly. This is but one of the many questions which astronomers are trying to answer.



Courtesy of the Carnegie Institution of Washington

FIG. 101. The relative sizes of the nine planets.

How do the planets compare in weight with water? Astronomers have calculated the density of the planets. Mercury, Venus, Earth, and Mars are about five times as dense as water; that is, each of these planets is about five times as heavy as a body of the same size composed entirely of water. Astronomers believe that Mercury, Venus, and Mars are solid spheres much like our own earth.

The density of the other planets is much less. The lightest is Saturn, which weighs less than a globe of water of the same size. It is thought that the larger and less dense planets are composed mainly of vapors surrounding a semi-liquid interior.

Although the materials of the planets are relatively cool compared with the sun and the planets themselves are seen only by reflected sunlight, it is thought by some that those farther away from the sun are less dense because they have not cooled off as much as those nearer the sun.

Facts about the planets. Figure 101 shows the relative sizes of the nine planets. The table below gives not only the sizes of the planets, but also other interesting facts about them.

Name of planet	*Average distance from the sun in miles*	*Diameter in miles*	*Revolution around the sun in years*	*Rotation on axis*	*No. of moons*
Mercury	36,000,000	3,000	.24	Uncertain	0
Venus	67,200,000	7,726	.62	Uncertain	0
Earth	92,900,000	7,927	1.00	24 hr.	1
Mars	141,500,000	4,200	1.88	24 hr. 37 min.	2
Jupiter	483,300,000	88,700	11.86	9 hr. 55 min.	9
Saturn	886,100,000	75,100	29.46	10 hr. 14 min.	9
Uranus	1,782,800,000	30,900	84.02	Uncertain	4
Neptune	2,793,500,000	33,900	164.78	Uncertain	1
Pluto	4,000,000,000(?)	7,000(?)	247.69	Unknown	Unknown

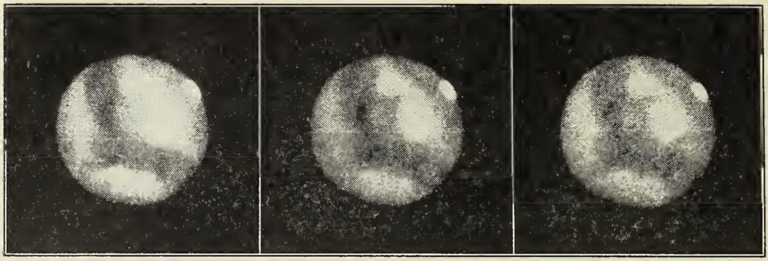
Mercury, the speedy planet. As Mercury is the planet nearest the sun and as it is always between us and the sun, it can be seen only shortly after sunset and shortly before sunrise. The time of year when Mercury can be seen best is March and April, when it appears like a bright star near the point of the horizon where the sun is rising or setting. (All observations in this unit as to time of year when heavenly bodies appear are taken from the standpoint of places in the northern hemisphere.) It travels swiftly in its orbit, making a complete revolution around the sun in eighty-eight days. This planet received its name because of the speed with which it travels around the sun, for in Greek mythology Mercury was the messenger of the gods, darting swiftly from place to place on their errands.

Astronomers believe that this planet keeps the same hemisphere toward the sun at all times. If it does, the hemisphere that receives sunlight would, because of nearness to the sun, be almost hot enough to melt tin (449° F.). Bread or cake exposed to the sunlight on Mercury would bake in a few minutes and, if not carefully watched, would soon be burned to a cinder. By contrast, the hemisphere that is in perpetual darkness would be so cold that the air we know would be changed into a solid in a very short time.

Venus, the queen of the planets. As this planet is the brightest it is the most conspicuous of the planets. It is named after the Roman goddess of love and beauty, and is probably more nearly like the earth than any other planet. During the late summer and early autumn it may be seen as a bright evening "star" at a point in the sky near the place where the sun sets. Its brightness is probably due to the reflection of sunlight from great banks of vapor or clouds that surround the planet. Perhaps you have, after sundown, noticed the effect produced by sunlight reflected from a fleecy white cloud.

Although Venus when nearest the earth is 25.7 million miles away, it is always much nearer the earth than any other planet. Its diameter is about 7726 miles. Venus revolves in its orbit around the sun in seven and one-half of our months, that is, 225 of our days. Because of its dense atmosphere, its brightness, and the absence of fixed markings, astronomers have not been able to agree upon the length of its day; observations support the view that the same hemisphere of Venus is always toward the sun.

Mars, the warrior planet. Because of its reddish color, and red is associated with war, this planet was named after Mars, the Roman god of war. Astronomers have been especially interested in Mars. When at the point in its orbit nearest the earth, it is only 48.6 million miles away and can be seen distinctly with the unaided eye. Through a telescope it appears as a broad red globe resembling a fiery orange. At the poles, patches of white are seen, a fact which has led some astronomers to believe that the poles are covered with ice and snow. The remaining surface of Mars has a reddish color except



Courtesy Yerkes Observatory

Fig. 102. Three views of Mars. Observe the white caps near the same pole. Some astronomers think it is a snow cap because it appears and disappears at different seasons.

for dark greenish-blue patches (Fig. 102). Markings, which appear to be definite lines, are also seen on this planet. These lines are spoken of as "canals," and their arrangement has led some astronomers to wonder whether they were not built by beings similar to ourselves.

Mars has two moons, one of which travels so fast in its orbit that it goes around the planet three times in one day.

Mars rotates on its axis once in 24 hours and 37 minutes, making a day there just 37 minutes longer than a day on earth. Mars has an atmosphere, but it is probably less dense than the atmosphere of the earth. It is argued, too, that since the axis of Mars inclines to its orbit much as the axis of the earth inclines to its orbit, the seasons there must be very much like those on the earth. Regardless of these facts, however, most astronomers think Mars to be uninhabited.

Jupiter, the giant planet. Jupiter is brighter than any other planet except Venus. Jupiter is the largest of the planets—its volume is about 1300 times that of our earth. Jupiter rotates on its axis once in nine hours and fifty-five minutes. Its rapid rotation has caused it to be very much flattened at its poles.

During the late summer and early fall Jupiter is seen as an "evening star" in the western sky, and during the late winter and early spring as a "morning star" in the eastern sky. With a small telescope we can see at least four of the nine moons of Jupiter. One of these four moons is larger than the planet Mercury and requires a week to travel once around the giant planet. These four moons are of especial interest to scientists because it is believed they were the first heavenly bodies discovered by the aid of the telescope. This was in 1610, and the discovery was made by Galileo with a telescope that would seem very crude to us. When he first saw these four large moons revolving about Jupiter, he at once exclaimed, "this is the way the earth travels around the sun!" But other people, even after seeing for themselves, would not believe this; they thought that he had bewitched either the telescope or their eyes. At that time most people believed that the earth was the center of the universe and that the sun and all the other heavenly bodies revolved around it.

Jupiter has at least five other moons. One of them, which is close to the planet, revolves about it in less than twelve hours. The remaining four are so small and so far from the planet that they are difficult to observe with astronomical instruments.

Saturn, the planet that wears a halo. When Galileo viewed Saturn through his telescope, he was astonished to see what he thought to be three globes. Scientists have since discovered that this curious appearance is caused by rings. These rings, three in number, are formed by particles of matter revolving about the planet. Studies of these rings by the aid of the spectroscope prove that different parts of the rings move at different speeds. The innermost particles of the dark ring travel around the planet in about five hours, while the particles on the outside of the outer bright ring require one hundred thirty-seven hours to complete the circuit. In addition to these rings Saturn has nine moons.

Uranus, a planet found by a music-master. In 1781 William Herschel, a German musician and astronomer living in England, while examining the skies with a low-powered telescope made by himself, discovered a body which appeared to be a small disk. He thought it could not be a star since in a low-powered telescope a star would appear as a point of light in the sky. With a telescope of higher power he observed this disk closely for a few nights; as a result he came to the conclusion that this newly found body was moving among the stars. At first he thought it to be a comet, but after further observations he knew he had discovered another planet. This planet, Uranus, can be seen with the unaided eye if the atmosphere is clear and there is no moon. Uranus has four moons, is almost 1800 million miles from the sun, and requires eighty-four of our years to complete one revolution around the sun. Astronomers are not agreed as to the length of day on the planet, as it appears to be still in a gaseous state and without any visible fixed markings on its surface.

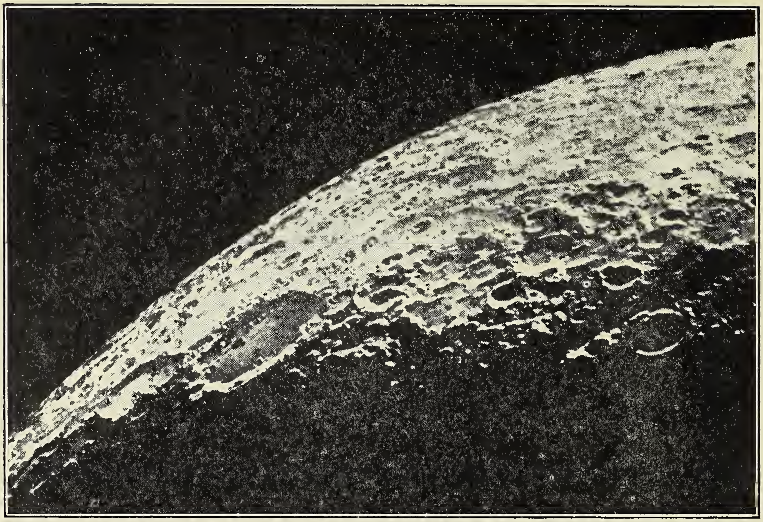
Neptune, the planet found by mathematics. The way in which Neptune was found shows how the use of mathematics solved an astronomical problem. Observations by astronomers showed that Uranus was not following the orbit in which astronomers figured it would travel. To account for this apparently strange movement, they concluded that there must be another planet, farther away from the sun, which was attracting Uranus from the path it ought to have followed. Two young astronomers, J. C. Adams of England and Joseph Leverrier of France, undertook to solve the problem. In 1846 both astronomers reached the same conclusions; they had figured mathematically the place in the sky where such a planet would have to be. Adams finished his work first; he asked the astronomers both at Cambridge and at the Royal Observatory at Greenwich to search the heavens for the planet, but as a chart of the stars in the region to be observed was not available, nothing could be done.

Leverrier wrote to a German astronomer, asking him to direct his telescope to a certain point in the heavens where he would discover another planet. The German did so, checking off every star in the field of his telescope against a chart of the stars in the region investigated. At last one bright uncharted spot remained. On the following night it was still there but had moved. Here was the unknown planet just where Adams and Leverrier had calculated by mathematics it would be.

Neptune requires nearly one hundred sixty-five of our years to revolve in its orbit once around the sun. It can be seen only with the aid of a telescope.

Pluto, the planet found by a camera. On March 13, 1930, the Lowell Observatory at Flagstaff, Arizona, announced the discovery of still another planet. This discovery was not an accident nor did it come as a surprise. Doctor Percival Lowell had been working on the problem for over twenty-five years prior to his death in 1916. Following the same mathematical procedure that had been used in locating the planet Neptune, Dr. Lowell had calculated that the new planet would be found in a certain place in the sky. The staff at the Lowell Observatory photographed this section of the sky according to Dr. Lowell's directions. On January 21, 1930, Clyde Tombaugh, a young assistant at the observatory, while washing a photographic plate, saw on the plate evidence of another member of the solar family. The staff could not be sure that it was another planet without further observations. During the weeks that followed careful observations were made and all calculations checked. About two months later the discovery was announced. The planet was acclaimed as the one whose location had been mathematically calculated by Doctor Lowell some years before. The name Pluto was chosen for this planet because the first two letters were Doctor Lowell's initials (Percival Lowell); it is also in keeping with the custom of naming planets after the Roman gods and goddesses. Pluto is about four billion miles from the sun and takes almost 248 years to travel once around the sun. Astronomers believe it is approximately the size of the earth and that it is made of material about as heavy as iron. On account of its distance from the sun, it receives almost no heat and light. In fact, astronomers have calculated that its temperature in sunlight would be 250° C. below zero or even lower. On account of its distance from the earth probably it will be impossible to determine whether or not it has any moons.

Planetoids, the baby planets. The space between the orbits of the planets Mars and Jupiter is so vast that astronomers wondered whether another planet might be found there. After searching with their telescopes they found not one planet but several hundred small bodies. These small bodies are known as *planetoids*, or asteroids; they range in size from that of huge boulders to bodies more than 100 miles in diameter. Ceres, the largest, has a diameter of about 400 miles. Eros, one of the small planetoids, has a diameter of from 15 to 20 miles and requires 643 days to



Courtesy of the Carnegie Institution of Washington

FIG. 103. Part of the moon's surface showing depressions and elevations.

complete its journey around the sun. Each of the planetoids has its own orbit. The time it takes them to travel once around the sun varies from twenty-one months to nine years.

These bodies are interesting chiefly because of the speculation about their origin. It would seem that when the solar system was born, something happened to a planet in process of formation that caused it to explode or burst; the planetoids may have resulted from some such disaster.

The earth, our own planet. Because we live upon the earth, ordinarily we do not think of it as one of the planets. As the earth is a planet it also revolves around the sun. Its orbit lies between those of Venus and Mars. The earth is almost 93,000,000 miles from the sun; it takes the earth one year to travel in its orbit once around the sun. It has one satellite, the moon. The movements of the earth will be studied in the next chapter.

The moon. The diameter of the moon is 2163 miles, and its distance from the earth is about 240,000 miles. Although the full moon may appear bright on a clear night, it shines, like the planets, by light reflected from the sun. Sunlight, however, is

400,000 times as bright as moonlight. So far as astronomers can tell, the moon is without an atmosphere or water. As a result, it is without fog or clouds, and consequently with a telescope we are able to see clearly its rough, barren surface (Fig. 103). Why does the moon appear like a disk?

What are phases of the moon? The moon revolves in its orbit around the earth once in 27.32 days. What we call a month is really a "moonth," the time it takes the moon to go around the earth. The same hemisphere of the moon always faces the earth; we never see the other hemisphere. However, the hemisphere of the moon facing the earth is not always facing the sun. There is a period of time when a place on the moon is in the sunlight and a period when that same place is in darkness. Find IA on the moon (Fig. 104). Is it in darkness? IIA? IIIA? IVA?

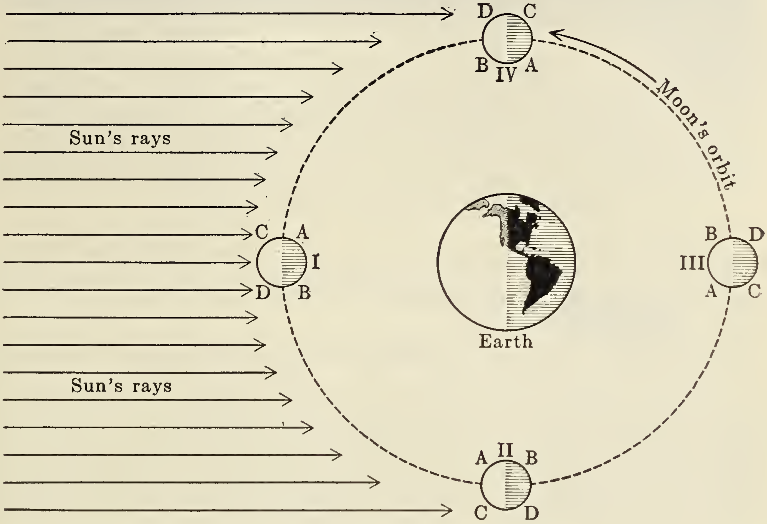
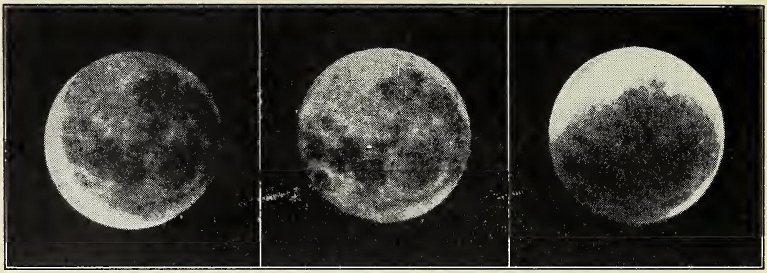


FIG. 104. Phases of the moon. How much of the moon can you see when it is at I in its orbit? II? III? and IV? Why is no more of its surface visible when it is at one of these places?

At the time of the new moon (I), the moon is between the earth and the sun. Do the rays of the sun strike any part of that hemisphere of the moon which is visible from the earth?



Courtesy Yerkes Observatory

FIG. 105. At the left is shown the new moon with the old moon (the dark part) in its arms. The crescent of the new moon (the light part) is lighted directly by the sun: the remainder (the dark part) is dimly lighted by reflection from the earth. In the center is shown the full moon lighted directly from the sun. At the right is the moon totally eclipsed, with the edge illuminated by refracted sunlight (page 411).

During this phase of the moon, no light is reflected from its surface to us, hence we cannot see the moon and we say it is the "dark of the moon."

Gradually as the moon continues in its orbit around the earth, more of the hemisphere which can be seen from the earth receives light from the sun. At first we see only a thin crescent. Each night a little more is visible. At the end of seven days about one-half of the hemisphere which can be seen from the earth is lighted by the sun, and then we say that the moon is in the *first quarter* (II).

As the moon continues in its orbit, more and more of the hemisphere facing the earth receives light from the sun until finally the entire hemisphere is lighted and then we say that the moon is "full" (III). As the moon continues on its journey, the visible part becomes less and less until it reaches its *third quarter* (IV). Finally the "dark of the moon" is reached again; and the moon begins another journey in its orbit around the earth.

Frequently during the period of a new moon, when a thin crescent is clearly visible, the points of the crescent are joined by a curved line of light which gives a faint outline of the entire hemisphere of the moon facing the earth (Fig. 105). This faint line is caused by the reflection of sunlight from the earth to the moon.

What causes an eclipse? While the sun is shining upon one hemisphere of the earth the other hemisphere is in darkness, and a cone-shaped shadow is cast out into space. When the moon on its journey around the earth passes through this shadow, we cannot see it and we say there is an eclipse of the moon. The moon likewise casts a shadow, and when, on its journey, it passes between the sun and the earth so that its shadow strikes the earth we cannot see the sun and we say there is an eclipse of the sun (Fig. 106). An eclipse of the sun casts a shadow over only a small part of the earth's surface (Fig. 107). Observers in this area can watch the progress of the eclipse (Fig. 108).

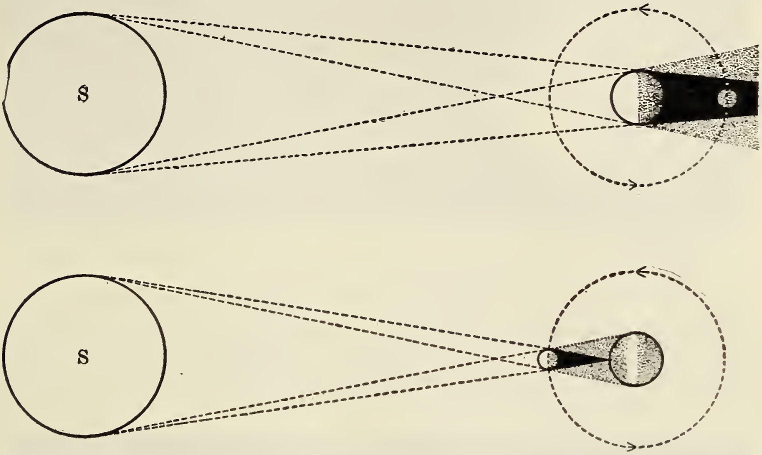


Fig. 106. The diagram at the top shows the relative positions of the sun, earth, and moon during an eclipse of the moon. The shadow of what body falls on the moon? The one below shows the relative positions of the sun, moon, and earth during an eclipse of the sun. The shadow of what body falls on the earth?

What causes the tides? When you throw a stone up into the air, the force of gravity begins to pull it back to the earth as soon as it leaves your hand. In the same way that the earth pulls on the stone, all bodies in the universe exert a pull (attraction) on one another. Because the moon is comparatively near the earth, it exerts a considerable pull upon it but rocks and stone and soil are not visibly affected by this pull. The waters of the sea are visibly affected as they are more free to move. The pull of the moon causes the level of the water to rise on the hemisphere of the earth facing the moon (Fig. 109). This rise of water is called a *tide*. You will notice that there is also a corresponding tide on the hemisphere of the earth turned away from the moon. This tide

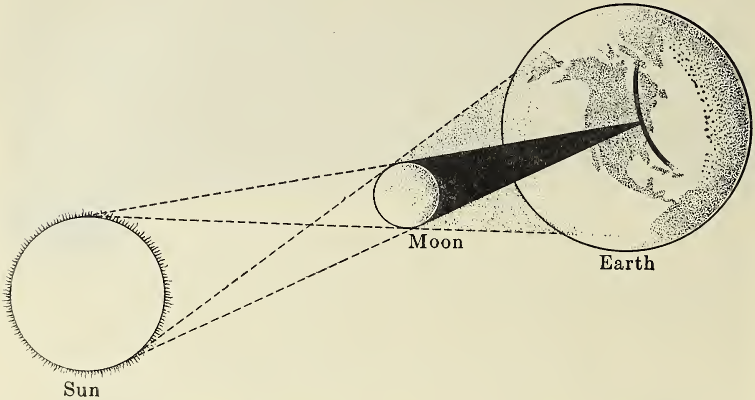
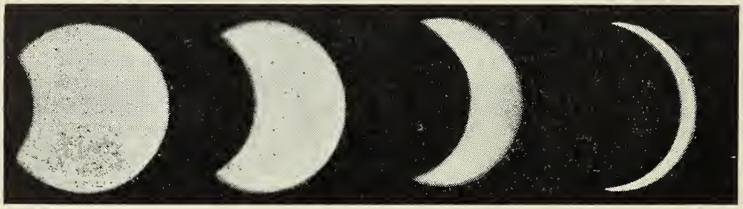


Fig. 107. The eclipse of August 31, 1932, threw a shadow over a narrow strip of the earth in the northeastern part of North America and adjacent waters as you can see from this drawing. If you had been in this strip during this eclipse would you have been able to see the sun or any part of it?



Photos by Johnson & Son, Boise, Idaho

Fig. 108. The light areas in this illustration show the progress of an eclipse of the sun that occurred on April 28, 1930. The eclipse could be seen in the western part of the United States. The photographs from which the illustration was made were taken near Mountain Home, Idaho. The light area on the left shows what part of the sun was visible at 11:10 A.M. The next one to the right shows the sun as it appeared at 11:27 A.M. The others show the sun at 11:51 A.M. and at 12:14 P.M.

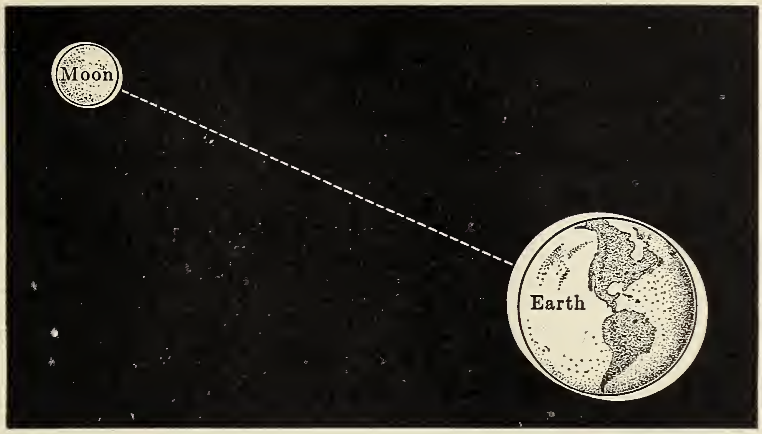


FIG. 109. Tell how this diagram helps you to understand that tides are due to the attraction of the moon.

occurs because the attraction of the moon pulls the earth away from the water of this hemisphere. This is easier to understand if you will remember what happens when you are in a car which starts suddenly. The car is pulled away from you and you are thrown backward. In somewhat the same way the moon pulls the earth away from the water on the hemisphere farthest from it, thus producing a tide on that hemisphere.

As the earth rotates the tide follows the moon until it reaches the shore. You can observe tides in bays and the mouths of rivers as well as on the coasts of the open sea. An incoming tide is called a *flood tide* and an outgoing tide is called an *ebb tide.* Since there are corresponding tides on the opposite sides of the earth, the statement is frequently made that flood and ebb tides occur in succession twice in every twenty-four hours. However, since the moon rises about an hour later each night, it really takes nearly twenty-five hours for two consecutive and complete flood and ebb tides.

The sun, like the moon, exerts a pull on the earth. When the sun and moon are on the same side of the earth they pull in the same direction; as a result the flood tides are higher and the ebb tides are lower. When the sun and the moon are on opposite sides of the earth, the tides are also higher than at other times. The moon has caused a tide on the side of the earth farthest from it and the sun increases this tide by pulling the water still farther away from the earth. These unusually high tides are called *spring tides* (Fig. 110). They occur twice in each month.

When the sun and the moon are acting at right angles to each other, the flood tides are lowest; they are called *neap tides.* Explain the action of the sun and moon at the time of neap tides.

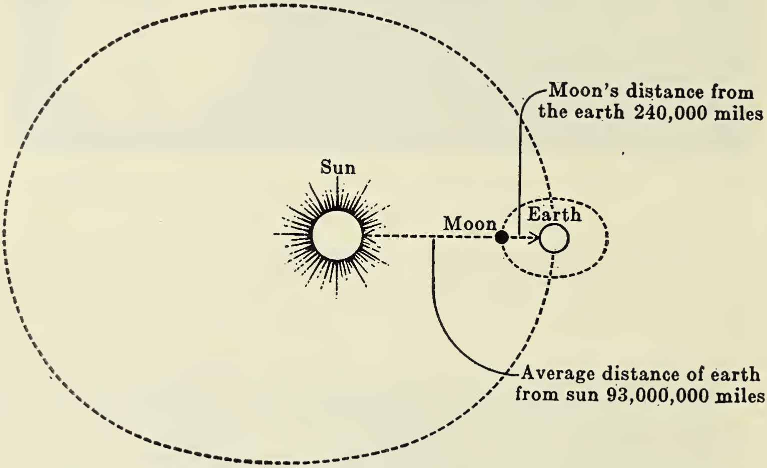

Moon's distance from the earth 240,000 miles
Sun
Moon
Earth
Average distance of earth from sun 93,000,000 miles

FIG. 110. Note in what position the sun and moon are in relation to the earth at the time of the spring tides. Why are not the tides so high at other times? Make a drawing to show the sun and moon acting at right angles.

The character of a sea coast has a great deal to do with the height of tides. The highest known tides occur in the Bay of Fundy. The shape of this bay is such that the incoming tide is confined within narrower and narrower limits, thus causing the water to rise higher and higher until at the head of the bay the tide has been known to rise sixty and even seventy feet.

Would you expect a steady wind to affect the height of a tide on any particular day? Explain.

Ships often take advantage of the tides. They frequently sail and dock at high tide and leave a river port with an ebb tide. Have you ever heard that a ship aground was floated at high tide?

PROBLEM: WHAT ARE SOME OF THE NEIGHBORS OF THE SOLAR SYSTEM, AND SOME OF ITS VISITORS?

The stars. Besides our sun there are millions of other suns in the universe, all sending us small amounts of heat and light. These other suns we call *stars.* While we speak of them as "little" stars, they really are not small; they only seem so because they are so much farther away than the sun. Astronomers have determined that many of these stars are millions of times larger than the sun and much hotter. Usually the stars can be seen only on a clear night; in the daytime the much brighter light of the sun obscures them in much the same way that sunlight obscures the light from a burning candle which at night can be seen from a considerable distance. When the sun is obscured by a total eclipse we can see the stars, but as soon as the eclipse has passed, the light from the stars is not bright enough for them to be seen in sunlight.

How far from the earth are the stars? To get some idea of the distance of the stars from the earth, let us consider one of the nearest—Alpha Centauri. If it were possible for us to travel continuously at the rate of 55 miles per hour from the earth toward this star, we would not reach it until about 55,000,000 years had passed. Sirius, called the "Dog Star," another near neighbor of the earth, is almost double the distance of Alpha Centauri. These distances in space are so great that we cannot even imagine them. When we compare them with the greatest distance on the earth (25,000 miles around the earth at the equator) we still cannot form a clear idea of the vastness of space.

In order to measure distance in space, astronomers use the *light year.* A light year is the distance light travels in one year. As the speed of light is 186,284 miles per second, how many miles does light travel in a year? Using the light year as a unit to measure distance in space, we find that Alpha Centauri is 4.31 light years distant from the earth and the star Sirius is 8.7.

Though larger than the sun (Fig. 111), the stars seem small because, owing to these inconceivably great distances, only a tiny bit of the total light that each one gives off ever reaches us.

Why do stars appear as tiny points of light instead of disks of light?

It is interesting to note here that the earth receives some energy from the stars. In the summer of 1933 light energy from the star Arcturus was used to turn on the electric lights at the Century of Progress Fair in Chicago. This use of light energy seems almost incredible when we consider that the distance from Arcturus to the earth is 41 light years. In other words, the light energy used in the summer of 1933 at Chicago started on its journey from Arcturus to the earth in the summer of 1892.

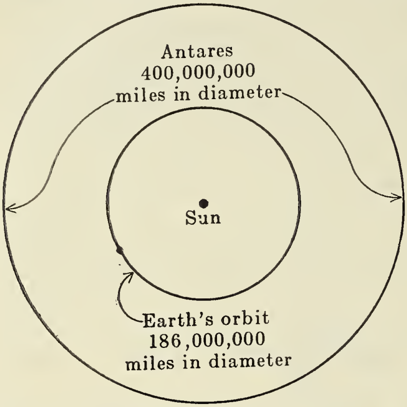
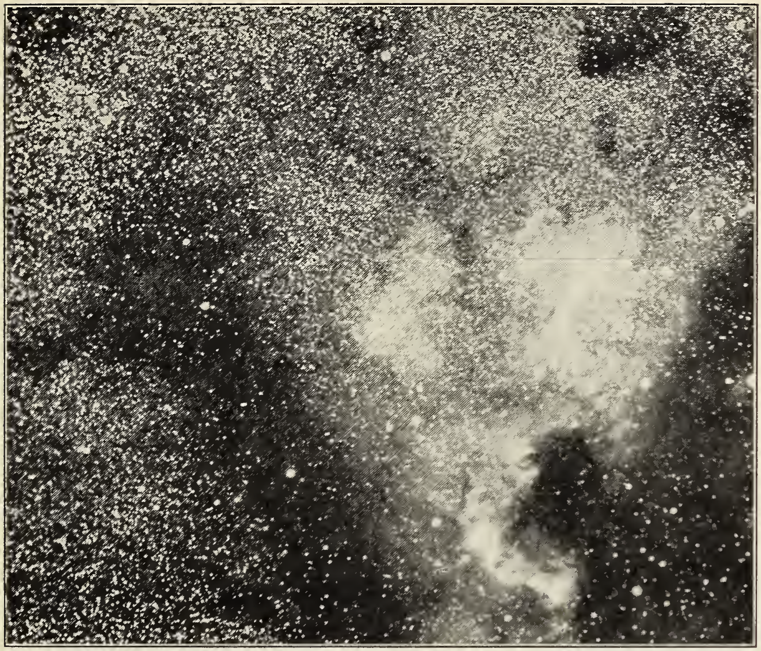


Fig. 111. Compare the diameter of the giant star Antares with the average diameter of the earth's orbit. The sun is so small when compared with this great star that it had to be represented by a dot.

How many stars are there? "As numberless as the stars" is an expression that means more each time a more powerful telescope is built (Fig. 112). With the naked eye we can see on a clear moonless night about 3000 stars. In the entire sky, that is, in both northern and southern hemispheres about 6000 stars are visible to the naked eye. According to Jeans, a 100-inch reflector telescope equipped with sensitive photographic plates would show thousands of millions of millions of stars. He says further that the total number of stars in the universe must be something like the total number of specks of dust in London.

Do the stars revolve about the earth? Owing to the rotation of the earth, all the stars appear to revolve about the earth. Those visible in the northern hemisphere appear to revolve around one star, the North Star, somewhat as the continents on a globe seem to revolve around the North Pole as the globe is turned. They complete their apparent revolution around the North Star in a little less than twenty-four hours. In reality it



Courtesy Yerkes Observatory

FIG. 112. "As numberless as the stars." Observe that some of them appear to be in clusters. Notice also the great gaseous body sometimes called the "North America" nebula.

is the rotation of the earth on its axis that makes the stars appear to revolve about the earth.

In the northern hemisphere some of the bright stars that can be seen are the North Star, Capella, Vega, Arcturus, and Altair. Locate these stars in Figure 113, and then at the first opportunity try to find them in the sky.

The brightest star in the sky is Sirius, the "Dog Star." To people in the United States this star is visible in the southern sky during the winter months. Sirius is interesting because astronomers believe that its surface temperature is nearly twice that of the sun. It gives off twenty-six times as much light as the sun and it is large enough to make four bodies the size of our sun. At your first opportunity try to locate this star in the sky.

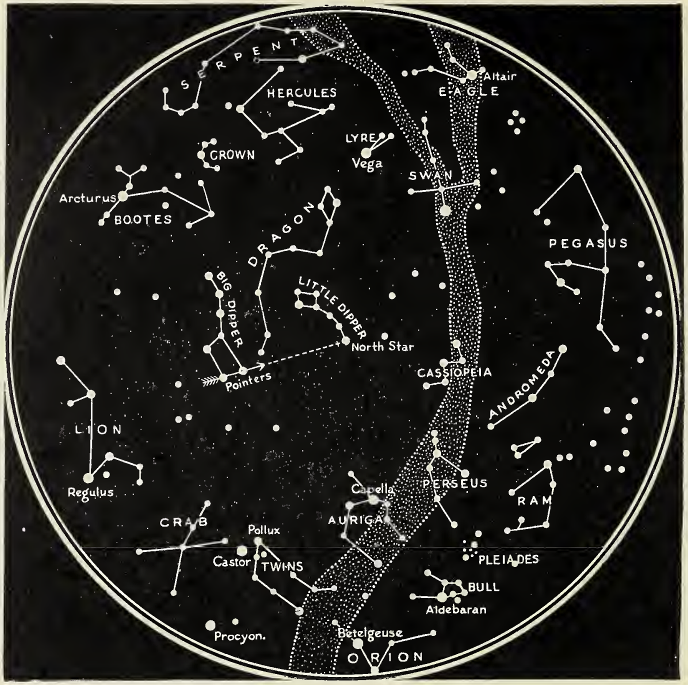


FIG. 113. Constellations of the northern hemisphere. After you have studied this drawing see how many of these constellations you can recognize on a night when the sky is clear.

What is a constellation? Thousands of years ago shepherds watching their flocks by night and sailors gazing into the heavens noticed certain groups of bright stars that seemed to remain at the same distance from one another, i.e., in the same relative position. They named these groups of stars *constellations*, from a fancied resemblance to gods or heroes or animals. Although it is difficult for us today to see these resemblances, the constellations are still known by the names which those ancient observers gave them: Hercules, Perseus, Gemini (the Twins), Leo (the Lion), and so on.

The stars of the northern sky (Fig. 113) appear to revolve around the North Star in rather well-defined streams or belts.

Among the constellations included in the belt of stars nearest the North Star are: (1) the Great Bear, including the Big Dipper; (2) the Little Bear often called the Little Dipper, of which the North Star forms the end of the tail or handle; (3) Draco, the dragon; (4) Cassiopeia, the queen in her chair; (5) Perseus, the slayer of Medusa; (6) Auriga, the charioteer. Next to the first belt of stars that appear to revolve about the North Star is a second belt revolving in a larger circle. Some of the constellations in this belt are Orion (the Hunter), Hercules (the Warrior), Taurus (the Bull). These constellations can be seen most clearly in the winter months. The stars of these constellations appear to rise at a point due east and to cross the heavens to a point due west in about twelve hours.

In the southern hemisphere also there are many bright stars and beautiful constellations. The best known constellation is the beautiful Southern Cross. Because these stars are always below our horizon they are not visible to persons living in the northern hemisphere.

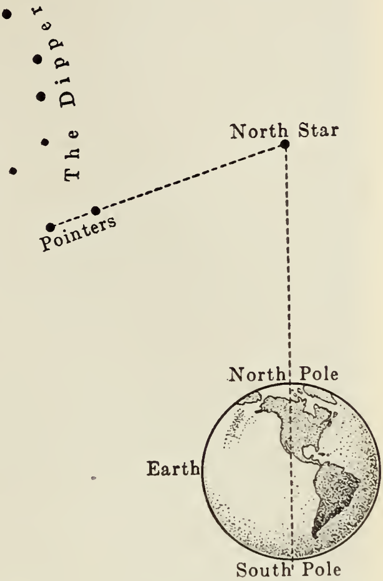


Fig. 114. Diagram showing relative positions of the North Star, the Big Dipper, and the earth.

Perhaps the best known constellation in the northern sky is the Big Dipper, which is part of the larger constellation called *Ursa Major* (Great Bear). The two stars on the side of the bowl opposite the handle are called "pointers" because, if we imagine a line drawn through the pointers and extended about five times the distance between them, it would appear to pass through, or very nearly through, the North Star, also called the Pole Star (Fig. 114).

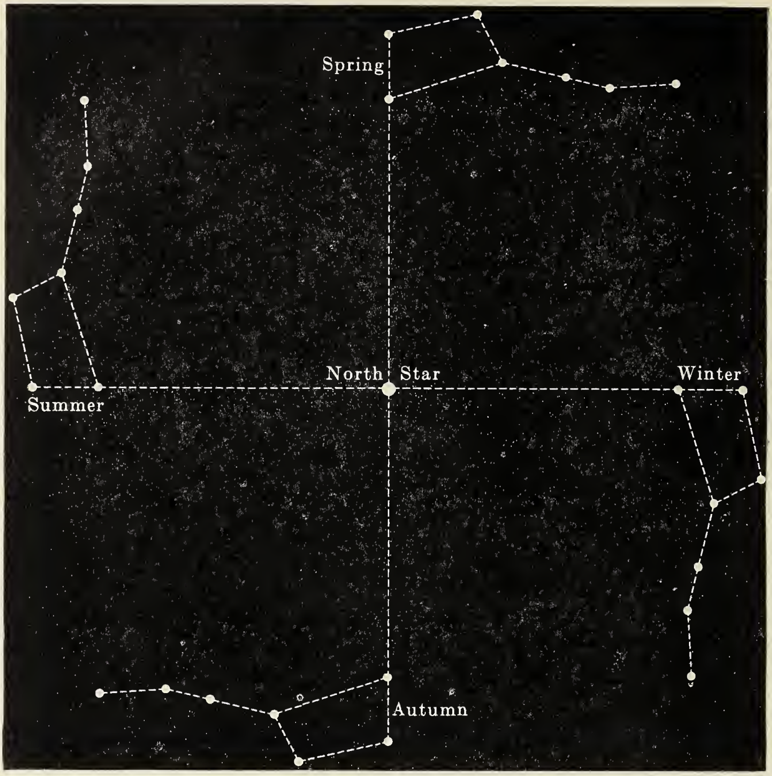
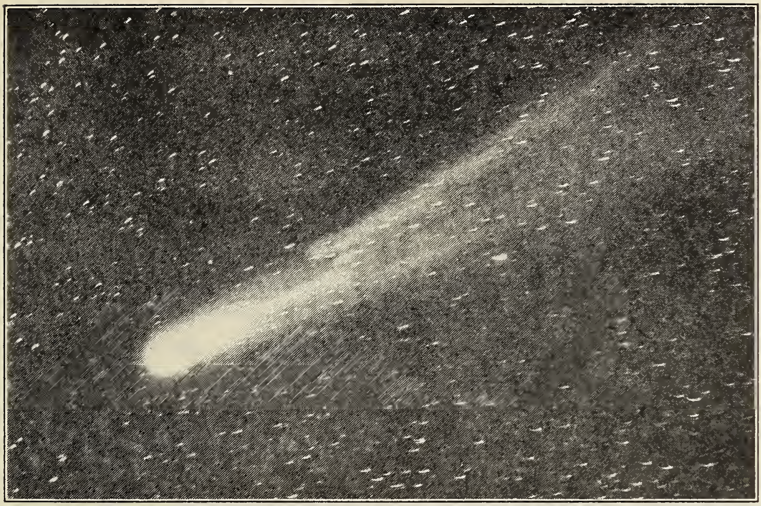


FIG. 115. Positions of the Big Dipper at the four different seasons of the year when viewed about 9 P.M. In what direction are you facing when you look at the North Star?

The North Star. Ever since ancient times this star has been a guide to navigators, travelers, and others. This star is so nearly in line with the axis of the earth that it always indicates almost due north. By means of the Big Dipper (Fig. 115) the North Star can easily be located on a clear night, and having found the North Star, the traveler knows which way is north and can set his course in any desired direction.

Go out early on a clear night and observe the stars above and below the North Star. About two or three hours later observe them again. You will notice that the stars above the North Star



Courtesy Yerkes Observatory

FIG. 116. Halley's Comet last seen in 1910. Why do the stars appear as streaks of light rather than as points?

appear to have moved from right to left (from east to west); and those below the North Star, from left to right (from west to east). Taken, as a whole, all the stars observed appear to have moved in a direction opposite to the movement of the hands of a clock, i.e., in a counterclockwise direction.

Special problem. From observation make a drawing of the Big Dipper; indicate the position of the North Star and give the date.

What is a comet? A comet never fails to excite our interest, especially if the heavenly visitor can be seen with the unaided eye. Comets, like planets, move in fixed orbits. When first seen as a faint speck in the sky, a comet is usually at about the same distance from the earth as Jupiter. The head of a comet, which seems to be a great cluster of particles resembling a swarm of bees, may be 30,000 to 100,000 miles in diameter. It appears brighter and brighter as the comet gets nearer and nearer the sun. Why? Gradually the tail comes into view (Fig. 116).

The tail of a comet is always on the side of the comet farthest from the sun. This fact may be explained by the theory that the very light gaseous material of which the comet is formed is repelled by sunlight. While a comet is approaching the sun, a tail streams after the head; but as it speeds away from the sun on its journey along its orbit, the comet throws its tail ahead like the rays from the headlight of a locomotive.

Using mathematics, astronomers have calculated the orbits of certain comets; from their calculations the time at which these visitors will reappear can be foretold accurately. This was true in the case of Halley's comet, which the parents of many of you have probably seen. Halley, an English astronomer, observed a great comet in 1682 while on a visit to Danzig. Sir Isaac Newton, a famous scientist living at that time, believed that comets travel in orbits. Newton's belief encouraged Halley to make a study of the orbits of comets. His first great discovery was that the comet seen by him in 1682 was the same comet that earlier astronomers observed in 1531 and in 1607, or at least that those comets traveled in the same orbit as the comet of 1682. So certain was he that it was the same comet that he predicted its return in 1758 or 1759. It did reappear in 1759. We know now that he could have foretold its return in 1835, and also in 1910. Mathematical calculations based on the observations of its motion in its orbit secured in 1910 indicate that this comet will return in 1986.

What is a meteor? Streaks of light sometimes seen in the sky at night are known as "falling stars." Astronomers tell us, however, that these streaks of light are caused by small bodies of material called *meteors,* which are drawn toward the earth with great speed by the force of gravity. The friction between a rapidly rushing meteor and air produces heat so intense that the meteor burns and gives off light.

Where these particles of matter came from is not known positively but perhaps they are remnants of comets. If a meteor reaches the earth, what remains of it is called a *meteorite.* In most instances, however, the heat generated by friction is great enough to burn up the meteor before it reaches the earth. Iron, nickel, cobalt, tin, copper, sulfur, and others of the elements have been found in meteorites. Sometimes a shower of meteors may be seen. One of these showers occurs regularly each year about August 10.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

astronomer
chromosphere
comet
constellation
corona
eclipse
Halley
Herschel
incandescence
Lowell
light year
meteor
meteorite
observatory
orbit
phase
planet
planetoid
photosphere
solar system
spectrum
spectroscope
sunspots
tide

Write the number of each item on your paper and after it the word that completes the statement.

1. Scientists have discovered that certain elements are in the sun by the aid of an instrument called a ________.

2. Eruptions on the surface of the sun produce ________.

3. The word planet comes from a Greek word which means ________.

4. The largest planet is ________.

5. The shadow of the ________ produces an eclipse of the sun.

6. A group of stars which was thought to resemble an animal or an ancient hero is called ________.

7. The last planet to be discovered was ________.

8. The planet whose orbit is between those of Venus and Mars is: Pluto; Vega; Earth; Neptune; Saturn.

Which item in each of the following lists does not belong with the others?

9. star; constellation; Orion; Sirius; stratosphere.

10. solar system; moon; North Star; earth; troposphere.

Which of these statements are true? If any are false, re-state them in correct form.

11. The atmosphere on the moon is much the same as the atmosphere on the earth.

12. The moon always presents the same hemisphere to the sun.

13. Planets shine by light reflected from the sun.

14. The sun is a planet.

15. A meteorite was at one time a meteor.

CHAPTER XII

HOW DOES MAN MEASURE TIME AND DETERMINE THE LOCATION OF A PLACE ON THE EARTH?

Do you know:

That the earth travels eighteen miles a second? What causes day and night? Why a year is the length it is? How to tell what years will be leap years?

What causes the seasons to change? How the change of seasons affects our lives? During what season the earth is nearest the sun?

How the captain of a ship can locate his position while at sea? How a sundial tells time? What standard time belt you live in? Why standard time belts were established?

PROBLEM: HOW DO DAY AND NIGHT AND THE LENGTH OF THE YEAR DEPEND UPON THE MOTIONS OF THE EARTH?

What are the motions of the earth? We have just studied the earth in its relation to the other members of the solar system. We will now find out what scientists have learned about the shape of the earth and its motions.

The earth has three principal motions, which are going on at the same time: (1) It is rotating on its axis. The time required for each rotation is twenty-four hours. This motion causes day and night. (2) It is *revolving* around the sun at the rate of eighteen and one-half miles per second. The time required to make one complete revolution is one year. This motion, together with the inclination of the earth's axis, causes the seasons. (3) The whole solar system including the earth is moving through space toward the constellation Hercules at the terrific speed of twelve miles per second.

As a result of the revolution of the earth around the sun and the movement of the entire solar system through space, the path which the earth travels is a spiral (Fig. 117). Astronomers believe that this third motion has no effect upon plant and animal life on the earth. Furthermore, since space is so vast and we are so many millions of miles away from the stars, we do not need to worry about the earth's colliding with other bodies.

You may have wondered how an astronomer can tell that the solar system is moving through space toward the constellation Hercules. John Herschel observed that the distance between the stars of this constellation was slowly increasing. The only way in which he could explain this phenomenon was to conclude that the solar system is traveling toward them. Explain why traveling toward two lights would make them seem to move apart.

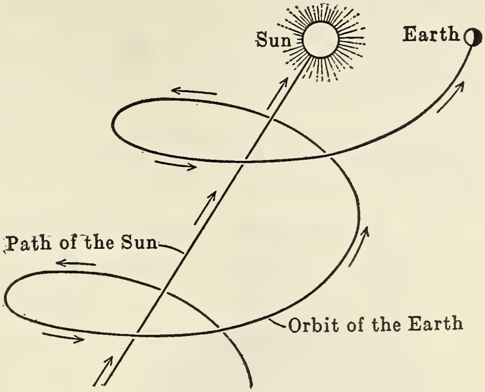


FIG. 117. As the earth revolves around the sun, the whole solar system is moving through space. These combined movements cause the earth to move in a spiral path.

What motion of the earth determines the year? The earth makes one complete journey in its orbit around the sun in 365 days, 5 hours, 48 minutes, and 46 seconds. This length of time is called a *year*. Julius Caesar, in the first century B.C., established the Roman calendar on the basis of 365 days in a year, including an extra day in every fourth year, or leap year, to take account of the 5 hours, 48 minutes and 46 seconds missed by each calendar year. You will notice, however, that 5 hours 48 minutes and 46 seconds is 11 minutes and 14 seconds less than one-quarter of a day. From the time of Julius Caesar to the time of Pope Gregory XIII (1582) this difference had brought the day of the year given by the calendar ten days ahead of the day of the year given by the position of the earth in its orbit. Consequently, it was necessary to drop ten days from the calendar. Why? The new calendar, called the Gregorian Calendar, is the one we use.

In order that such a situation shall not occur again, it has been agreed that every year exactly divisible by four is a leap year except the centennial years, years ending in two zeros. Still this does not quite take care of this difference in time, and therefore every centennial year that is exactly divisible by 400 is a leap year. Were the following centennial years leap years: 1700, 1800, 1900? Will the centennial year 2000 be a leap year? These corrections of the calendar make it agree with the position of the earth in its orbit.

What motion of the earth determines the day? The rotation of the earth on its axis carries us from morning sunlight into the darkness of evening and from darkness into morning sunlight again (Fig. 118). The time it takes the earth to rotate once on its axis is divided into twenty-four units of time called *hours*. The hour is divided into sixty equal units of time called *minutes*, and the minute is divided into sixty equal units called *seconds*. Of course, as you know, the number of hours of daylight varies with the season, but the length of a day is always twenty-four hours.

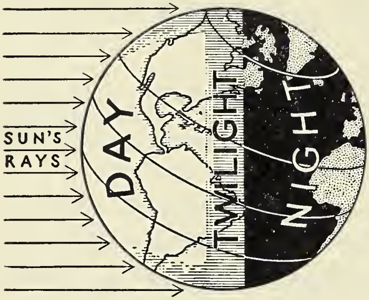


Fig. 118. The rotation of earth on its axis from West to East carries us from sunlight into darkness and from darkness into sunlight again.

What is the shape of the earth? We often speak of the earth as a sphere and, for our work, we may consider it as such. However, it is not a perfect sphere. It is slightly flattened at the poles.

Why does the earth have a spherical shape? Any liquid, if moving through a substance that is lighter in weight than it is, tends to assume a spherical shape. You know that a small drop of mercury (which does not wet the surfaces of the materials with which it comes in contact) assumes a spherical shape. In the early history of our country, lead shot was made by causing small streams of molten lead to drop from the top of a high tower into water. These streams broke up into molten drops which became spherical as they fell through the air. They kept this shape when they changed from a liquid to a solid form before reaching the water. In modern times, soap granules are made by spraying semi-liquid soap through small nozzles at the tops of tall towers. As it falls the height of the towers it forms into minute sphere-shaped particles (see Fig. 155).

✓ **Experiment 56. To show the shape of a drop of oil suspended in alcohol.** Pour water into a small beaker until it is more than half full. Now carefully pour some alcohol upon the water. Why does the alcohol remain in a layer above the water? With a medicine dropper insert a drop of olive oil into the lower part of the layer of alcohol (Fig. 119). What shape does the drop of oil assume?

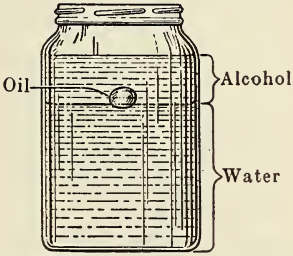


FIG. 119. A drop of oil floating as a sphere.

Experiments show that liquids assume the shape of a sphere while moving through materials lighter than themselves. A sphere is the most compact form that any mass can have. Explain. If the earth at some remote time was in a molten condition, as most scientists believe, the force of gravity acting on the particles of the mass as it moved through space caused the earth to assume the shape of a sphere.

Why is the earth flattened at the poles? The diameter of the earth at the poles (7899 miles) is 27 miles less than the diameter at the equator (7926 miles). You may have wondered why the earth is flattened at the poles; the following experiment will help you to understand.

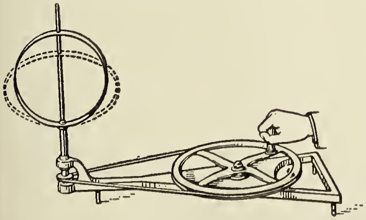


FIG. 120. How does this experiment furnish a possible explanation for the flattening of the earth at its poles?

√ **Experiment 57. To show the shape assumed by a rapidly rotating flexible hoop.** Procure a rotator with a flexible hoop (Fig. 120). What is the shape of the hoop? Rotate the hoop. What change occurs in its shape? Rotate it more rapidly. What further change occurs?

Just as the rotation of the flexible hoop caused it to flatten at its poles, so the rapid rotation of the molten earth may have been what caused it to flatten at the poles.

PROBLEM: WHAT CAUSES THE CHANGE OF SEASONS?

What motion of the earth causes the change of seasons? You learned in the previous chapter that the axis of the earth points toward the North Star. Although the axis of the earth always points toward the North Star, it tips toward the sun for a part of the year and away from the sun the rest of the year (Fig. 121). The change in the tipping of the earth's axis is due to the motion of the earth in its orbit. This leaning position of the axis is called the *inclination of the earth's axis.* The motion of the earth in its orbit around the sun together with the inclination of the earth's axis causes the change from one season to another. Let us see how these two factors bring about the change of seasons.

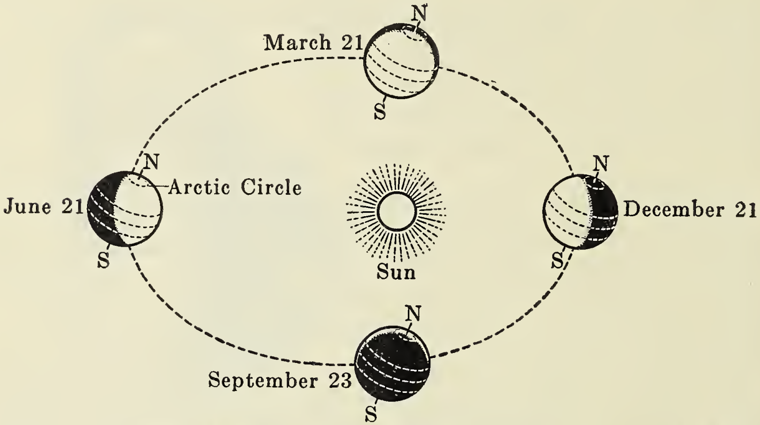


FIG. 121. Change of seasons. Explain from this diagram the length of day and night at the opening of each season; also, the cause of change of seasons. During what season is the earth nearest the sun?

As the earth travels around the sun in its orbit, the inclination of the earth's axis causes some parts of the earth's surface to receive more heat than others. A study of Figures 121 and 122 will show why they do. Figure 121 shows that the northern hemisphere upon which we live, tips the most toward the sun on June 21. Consequently, on this day in the north temperate zone the sun's rays are more nearly vertical as they fall upon the earth's surface than at any other time. The heating effect of a vertical ray of sunlight is much greater than that of a slanting (oblique) ray. Notice (Fig. 122) that equal amounts of sunlight *A* and *B* are falling upon the circle representing the earth, but that the vertical rays of sunlight *B* fall upon a much smaller part of the circle than the oblique rays *A*. Since the energy from a vertical ray is concentrated upon a much smaller area than an equal amount of energy from an oblique ray, it has a much greater heating effect.

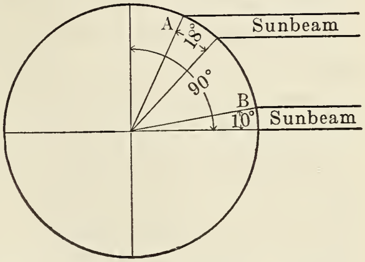


FIG. 122. The heating effects of sunlight at different places on the earth.

The only parts of the earth's surface that ever receive vertical rays from the sun lie between the tropics of Cancer and Capricorn, the Torrid zone. All other parts of the earth receive oblique rays only. This means, of course, that the Torrid zone is the warmest region of the earth.

Notice (Fig. 121) that on March 21 the position of the earth in its orbit is such that the equator receives the vertical rays of the sun. At this time the number of hours of daylight and darkness are equal at every point on the earth. Why? This is the first day of the season called *spring*.

As the earth revolves in its orbit, it moves toward the position marked June 21. On this date the vertical rays of the sun fall upon the tropic of Cancer. This means that the rays of sunlight received on parts of the earth north of the tropic of Cancer have become less oblique and consequently more heat is received from the sun. Why? Notice, too, that when the earth is in this position the hours of daylight are longer than the hours of darkness. Why? June 21 is the longest day of the year in the northern hemisphere. On this day *summer* begins.

During this part of the earth's journey, what change is occurring in the direction of rays received from the sun in the southern hemisphere? Has the temperature become higher or lower? How have the hours of daylight and darkness changed? On June 21, what season begins in the southern hemisphere?

As the earth revolves in its orbit, it moves toward the position marked September 23. During this period the vertical rays of the sun are received by parts farther and farther south until once again the equator receives vertical rays.

During this period what change is occurring in the direction of rays received on the northern hemisphere? The northern hemisphere, then, is receiving less and less heat from the sun. What change is occurring in the hours of daylight and darkness? On September 23, the season of *autumn* begins. On this date, day and night are again equal in length at every point on the earth.

Trace the changes in the kind of rays received from the sun and the hours of daylight and darkness on the southern hemisphere during this period.

As the earth continues in its orbit toward the position marked December 21, the vertical rays of the sun are received by points farther and farther south until on this date vertical rays are received on the tropic of Capricorn. During this period the rays received by points on the northern hemisphere are more and more oblique. What change is occurring in the amount of heat received? What change occurs in the hours of daylight and darkness? On December 21, *winter* begins on the northern hemisphere.

Trace the changes during this period on the southern hemisphere.

As the earth completes its journey in its orbit to the position marked March 21, trace the changes in the kind of rays received from the sun on the northern hemisphere, and the corresponding changes in amount of heat received and the length of the hours of daylight and darkness.

How long has it taken the earth to make a complete revolution in its orbit?

The heat equator. Since both the sun and the earth have spherical surfaces, the strip on the earth upon which the vertical rays of the sun fall at any particular moment is so narrow that it can be referred to as a line. As you know, this line is called the *heat equator.* From the tropic of Cancer, which the heat equator reaches sometime after June 21, it moves south gradually, reaching the geographic equator about September 23 and the tropic of Capricorn, sometime after December 21. From here the heat equator moves north, reaching the geographic equator again about March 21 and the tropic of Cancer again after June 21 as before. From this you may conclude that in the northern hemisphere this imaginary line moves from north to south as the season changes from summer to winter and from south to north as the season changes from winter to summer. Describe the movements of the heat equator in the southern hemisphere. What temperatures prevail generally on the earth's surface between the tropics of Cancer and Capricorn? Why?

As the heat equator moves, will the wind belts of the earth move? Explain.

You have seen how the yearly journey of the earth, together with the inclination of the earth's axis, produces the great climatic changes called seasons which greatly influence the conditions under which we and all the other peoples of the earth live. How do these changes of season affect our lives in the northern hemisphere?

PROBLEM: HOW ARE LATITUDE AND LONGITUDE USED TO DETERMINE THE LOCATION OF A PLACE ON THE EARTH?

To assist us in locating places on the earth and in calculating time, lines are drawn on globes and maps to represent imaginary lines on the surface of the earth (Fig. 123). With these lines you are no doubt familiar. For example, the *equator* is the imaginary line that reaches around the earth midway between the north and south poles. The length of this line, the circumference of the earth, is about 25,000 miles.

What are parallels? The equator is, of course, a circle. To the north of the equator are drawn 90 circles parallel to it; to the south of the equator are drawn 90 other circles parallel to it. These circles are called *parallels* because they are parallel to the equator. The distance between one of these parallels and the next is one degree, that is one-ninetieth of the distance between the equator and the North or South pole. Find the parallel on Figure 123 that is 20° north of the equator; the one that is 40° south.

Certain parallels have been given special names. The tropics of Cancer and Capricorn are parallels. Locate them on the map. The Arctic and Antarctic circles are parallels. Locate them.

What is the latitude of a place on the earth? Parallels are used to measure *latitude*, that is distance north or south of the equator. Find the parallel on Figure 123 that is 30° north of the equator. The latitude of all places through which this parallel runs is 30° North. Where are all places whose latitude is 60° South?

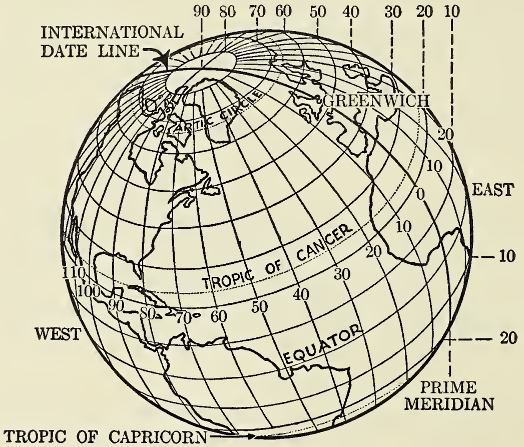


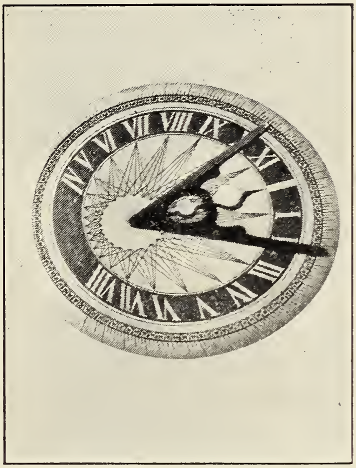
FIG. 123. Parallels and meridians. On a map of the United States find the parallel and the meridian nearest your home. What, therefore, is your latitude and longitude?

What are meridians? Notice the lines on Figure 123 running north and south. These are called *meridians*. They extend from the north to the south pole through the equator. The meridian running through Greenwich, England, is the *prime meridian*, or zero meridian. Find the meridian 10° east of the prime meridian; 40° west.

What is the longitude of any place on the earth? Meridians are used to measure *longitude*, that is distance east or west of the prime meridian. Find the meridian on Figure 123 that is 20° west of the prime meridian; the longitude of all places on this meridian is 20° West. Where are all places whose longitude is 70° East?

How a place on the earth can be located. If you know the latitude and longitude of any place on the earth, you can locate it on a map. If a ship at sea is at 20° north latitude and 40° west longitude, find its position on Figure 123. What is the latitude and longitude of the town where you live? Why could you not locate a place if only its latitude were known?

How is time measured? As you have learned, the length of a day is measured by one rotation of the earth. Before clocks were invented, the length of one day was shown by a sundial (Fig. 124). From noon (the time when the sun casts its shortest shadow) on one day until noon on the next day is considered one (solar) day. The time of day or night indicated by a particular meridian as the earth rotates is known as *sun time.*



Ewing Galloway

FIG. 124. What time is it by this sundial? Would it be useful indoors?

How is time connected with meridians? Since in twenty-four hours the earth makes a complete rotation, the time on each meridian must be four minutes ahead of the time on the next meridian to the west of it. (24 hours = 1440 minutes. 1440 ÷ 360 = 4 minutes.)

What is standard time? Different places on the same meridian have the same sun time. Why? Different places on the same parallel have a different sun time. Why? In operating railroads that crossed the country from east to west, the difference in sun time of places along the route was confusing, as the time shown by a watch was either ahead or behind sun time. If a person traveled west, his watch was ahead; if he traveled east, his watch was behind. Why? To avoid this confusion the government adopted *standard time.*

When standard time was adopted, the United States was divided into four time belts (Fig. 125). All places in each belt use the sun time of the meridian located in the middle of the belt. These central meridians are fifteen degrees of longitude apart in order that the time of each belt will be one hour behind the time of the belt to the east of it. Explain why the central meridians are made fifteen degrees apart, and not sixteen or twenty.

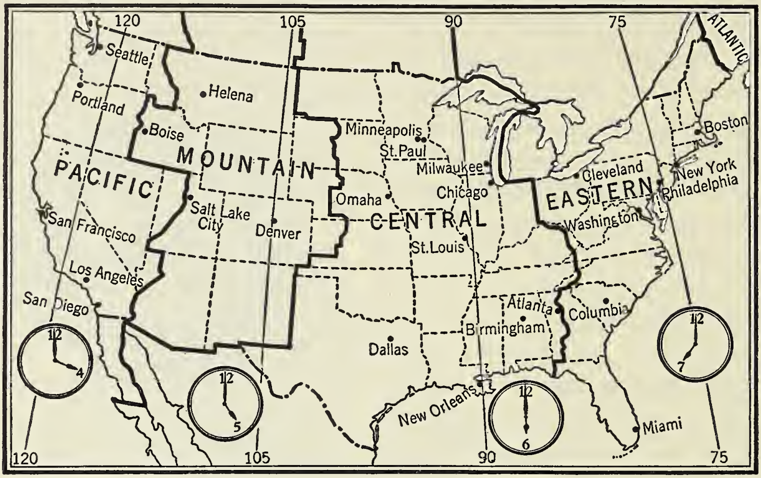


Fig. 125. Map showing the standard time belts in the United States. In which time belt is your home? When it is 8:00 A.M. standard time in your home, what time is it in New York? Chicago? Denver? Seattle? At what time would you tune in on a radio program broadcasted from New York City at 7:30 P.M. if you lived in Dallas? San Diego?

Of course, only those places situated on the central meridian have sun time; that is, on the central meridian the sun time and standard time are the same. In other parts of the time belt, standard time differs from sun time by not more than thirty minutes. Would the standard time of a place to the east of the central meridian be ahead or behind its sun time? A place to the west?

The names of the four time belts in the United States are Eastern, Central, Mountain, and Pacific. Their central meridians are respectively 75°, 90°, 105°, and 120° west longitude. The standard meridian for determining time in Alaska is 150° west longitude. Authority for readjusting boundary lines between time belts has been given by Congress to the Interstate Commerce Commission.

International date line. As you know, in order to keep correct standard time, you should set the hands of your watch back one hour as you travel west across a boundary line of a standard time zone. Traveling east you should set them forward one hour.

If you traveled west around the earth and "kept your calendar" by counting the number of days and nights which elapsed during your journey, you would find that your calendar will be one day "behind" a calendar kept by someone who stayed at your starting destination. If you traveled east, your calendar will be one day "ahead."

In order to avoid confusion in dates, it has become the practice at a particular imaginary line which extends from the north pole to the south pole for all eastbound travelers to repeat a day and westbound travelers to omit a day in their recording of time. This line coincides, in the main, with the 180th meridian. It crosses the Pacific Ocean in a place where few people live and is called the International Date Line (Fig. 123). By custom it has become the place where the navigators of ships bound east or west change the log of their ships. For example, on a ship which sails from San Francisco west and crosses the date line at 10 a.m. on Sunday, the log is changed to 10 a.m. Monday. To what day would the log of the ship be changed, if the ship were sailing east?

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

axis
calendar
degree
heat equator
imaginary line
inclination
latitude
leap year
longitude
meridian
parallel
revolution
rotation
season
sphere
standard time
sundial
time belt
tropic of Cancer
tropic of Capricorn

Write the number of each item on your paper and after it the word that completes the statement.

1. The earth has ________ principal motions.
2. The ________ of the earth on its axis produces day and night.
3. Lines on a globe parallel to the equator are called ________.
4. Distance north or south of the equator measured on meridians is called ________.
5. The northern hemisphere receives more heat from the sun in our summer than in our winter because of the inclination of the ________.
6. The line on which the sun's rays fall vertically at a given time is called the ________.
7. The United States is divided into ________ time belts.

Which item in each of the following lists does not belong with the others?

8. season; rotation of the earth; inclination of the earth's axis; vertical rays; revolution of the earth.
9. parallel; meridians; imaginary lines; equator; isobar.

Which of these statements are true? If any are false, re-state them in correct form.

10. Every fourth year is a leap year.
11. The northern hemisphere is more inclined toward the sun in our summer than in our winter.
12. The equatorial diameter of the earth is less than the polar diameter.
13. Distance measured in degrees east or west of a given meridian is called latitude.
14. All places on the same parallel have the same sun time.
15. A sundial measures standard time.

THOUGHT EXERCISES FOR UNIT V

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Day and night are caused by the rotation of the earth on its axis.

Questions or Problems

1. Why does the earth receive such a small part of the total energy radiated by the sun?
2. Why do astronomers believe that one half of the surface of Mercury is very cold?

3. Give reasons why some astronomers thought life existed on Mars.

4. How is the length of a day on the planets other than the earth determined?

5. Suggest a reason why Jupiter may be flatter at the poles than the earth.

6. Why do the sun's rays produce more heat on the earth in summer than in winter?

7. Explain what is meant by the midnight sun.

8. Why can a total eclipse of the sun be seen only by persons on a comparatively narrow strip of the earth's surface?

9. Explain how the inclination of the earth's axis exerts a vital influence upon your daily life.

Projects and Reports

1. Find out the latitude and longitude of your locality and report to the class.

2. If there is a sundial in your community, visit it and see if you can tell the time of day. Make a sundial and mount it so that it will show the time of day.

3. Look up the topic of "Daylight Saving Time." Make a full report to the class. Some things to be noted are: When was the movement started? Why was the movement started? What is "Daylight Saving"? Is it still used in some communities?

4. Study the life of Sir William Herschel. Be sure to tell in your report how the cooperation of his sister aided him in his astronomical observations, and to include a list of his contributions to astronomy.

5. Make a study of the surface of the moon. Mention theories as to the cause of its rough surface. What causes the "man in the moon"?

6. On a clear night, observe the northern sky. Draw a map locating the North Star and as many constellations as you can identify.

7. With the aid of star maps or almanac, make a survey of the heavens during the time which you study this unit. Locate any planets that may be visible and report their position to the class.

8. Make a study of the planet Mars and discuss the possibilities of human life existing there.

References for Reading and Study

1. Abbot, C. G., *The Earth and The Stars.* D. Van Nostrand and Company.

2. Barton, S. G., and Barton, W. H., *Guide to Constellations.* McGraw-Hill.

3. Baker, Robert H., *Introducing the Constellations.* The Viking Press.

4. Bragg, Sir Wm. H., *Concerning the Nature of Things.* Harper & Brothers.

5. Chant, C. A., *Our Wonderful Universe.* The Ryerson Press.

6. Eddington, Sir A. A., *The Nature of the Physical World.* The Macmillan Company.

7. Fath, Edward A., *Through the Telescope.* McGraw-Hill Book Company.

8. Fisher, Clyde, *Exploring the Heavens.* Thomas Y. Crowell Company, New York.

9. Forbes, George, *The Stars.* Cape Smith.

10. Gregory, Sir Richard, *The Vault of Heaven.* Metheun & Co., Ltd.

11. Hay, William T., *Through My Telescope.* E. P. Dutton and Company.

12. Ilin, M., *What Time Is It?* Lippincott.

13. Jeans, Sir J. H., *The Mysterious Universe.* The Macmillan Company.

14. Jeans, Sir J. H., *The Stars in Their Courses.* The Macmillan Company.

15. Moseley, E. L., *Trees, Stars, and Birds,* Part II. World Book Company.

16. Moseley, Edwin Lincoln, *Other Worlds.* D. Appleton-Century.

17. Reed, W. M., *Stars for Sam,* Chapter XXVIII. Harcourt, Brace & Company.

18. Swezey and Gable, *Boys' Book of Astronomy,* Chapters XI and XII. E. P. Dutton & Co., Inc.

UNIT VI

WHAT IS SOIL AND HOW IS IT FORMED?

Exploring the Changes in the Earth's Crust

Some time back through the ages, probably millions of years ago, the earth was formed. Where it came from and how it was formed no one knows. Scientists do not know what its condition was in the beginning. But we do know that it has become a sphere slightly flattened at the poles, with a highly heated interior, a solid outer crust with rivers, lakes and oceans, and entirely enveloped with a vast ocean of air. No doubt, in the beginning, the hard outer crust was composed entirely of rock.

You may rightly wonder and ask "If the earth's crust was composed of rocks, how did it become what it is today?" Of course, much of this question cannot be answered today, but scientists have learned a lot about these changes and how they were brought about. Scientists have concluded that the center of the earth is composed of highly heated rock, hot enough to flow like molten iron through openings in the earth's crust. During certain ages, this highly heated rock flowed out of cracks in the hard outer crust and filled great valleys and covered many parts of the earth's surface to a great depth. During the ages when these great outpourings of molten rock took place, mountains were thrown up, new ocean beds were formed and the surfaces of whole continents were changed.

Scientists also tell us that in the ages that followed, the newly formed rocks were broken up, mountains were torn down and carried into the sea. How could this have happened? To understand what happened you must think of the vast ocean of air as a gigantic grinding mill operated by an engine of millions of horse power. Of course, this huge engine is the sun. It evaporates water and heats the air over vast areas of the earth's surface.

From your study of weather, you know that evaporation of water and winds cause storms. Winds blowing with terrible force pick up loose particles of rock and carry them from place to place. Torrents of rain fall. Rivers rushing to the sea cut away mountains and break up rocks. The waves of the sea grind the rocks on the shore to fine sand. Rivers formed vast deltas and the drying up of lakes and other bodies of water formed great plains. Thus you can see by the action of heat, wind, and water how rocks were broken up and the mountains were cut down and the rock particles formed vast level plains and new ocean beds.

After ages of time, other mountains were thrown up and again torn down and carried to the sea. Ocean beds were thrust up and became level plains. During these ages, plants and animals came upon the earth. As the remains of dead plants and animals became mixed with rock particles, soil was formed. Trips through our country tell us also of vast caves, glaciers, volcanoes, geysers, and many other wonders in the crust of the earth today. You will understand, too, that heat, wind, and water are changing the earth's crust today as they did in ages past. This unit will tell you about these wonderful things, and it will show you, too, how you are dependent for your very life upon the soil that has been formed through the ages.

CHAPTER XIII

OF WHAT IS THE CRUST OF THE EARTH MADE AND HOW IS IT CHANGING?

Do you know:

That scientists can read the history of the earth in rocks? How many kinds of rocks there are? That Greenland once had a tropical climate?

That freezing water exerts a great force on every square inch of surface against which it presses? That glaciers sometimes carry huge boulders for many miles? How a canyon is cut by a river? How caves are formed? What causes the eruption of a volcano? Why the earth trembles during an earthquake?

PROBLEM: HOW HAS THE CRUST OF THE EARTH BEEN CHANGED?

How were rocks formed? Ever since the formation of the earth's crust, two gigantic systems of forces have been acting upon it: one to thrust it up in the form of great hills and mountains; the other to wear away the hills and mountains and reduce them to level plains.

As the earth's crust cooled, a great pressure was exerted by the molten material beneath. At times this pressure was strong enough to break through the original crust of igneous rock and vast quantities of molten material were thrown out. When this molten material cooled and solidified, it also became *igneous* rock.

The mountains did not remain unchanged; they were continually being worn down by the action of heat, rain, winds, and waves. Rock particles were carried by the rivers and deposited on the ocean beds. In some places these deposits were miles deep. The weight of the deposits cemented and consolidated the particles together into what is known as *sedimentary* rock.

These two systems of forces continued to act upon the earth's crust through countless ages. In the great upheavals, ocean depths were raised up and became dry land; hills disappeared beneath the surface of the water and became ocean beds. During these changes some of the igneous and sedimentary rocks were changed by heat and pressure into *metamorphic* rock.

Rocks, the book of the past. As the rivers flowed to the sea, some of the plant life of each age was carried along and deposited with the rock particles. As these rock particles were formed into sedimentary rock, the plants, together with the remains of plant and animal life of the oceans, were changed into *fossils* (page 213). Through the ages layer after layer of rock was laid down, each preserving fossils as a permanent record of the plant and animal life of that time. Later upheavals of the earth's crust lifted many of these rock layers above the surface of the ocean, enabling scientists to study the fossils and read the past history of our earth.

Scientists tell us that the layers of rock which were laid down in the very early life of our earth contain fossils of minute forms of plant and animal life. Layers of rock laid down ages later contain the fossils of huge plants and animals. Scientists believe that the atmosphere at that time contained much more carbon dioxide and moisture than it does now and the climate was much warmer. As you know, carbon dioxide is used by plants for food. Why should an abundance of carbon dioxide, moisture and heat lead to the growth of large plants? In many swampy regions the luxuriant plant growth of this period became covered with immense quantities of rock materials and in the ages that followed this plant material was changed into coal. During this same period the most gigantic animals that ever lived upon the earth, such as the brontosaurus (Fig. 205) and the diplodocus, roamed through the swamps and dense forests.

Rock layers in Greenland show that at one time it probably had a tropical climate. What do the coal beds of Alaska indicate about the climate there in some past age? North America has undergone great climatic changes; several ice sheets have passed over its northern and central parts, profoundly changing the rocky surface of the land and the plant and animal life.

Is the earth's crust being changed today? The same forces which have caused upheavals in the earth's crust and which have been wearing away the mountains are still at work. The forces that cause earthquakes and volcanic eruptions are examples of the forces that caused upheavals of certain parts of the solid crust. The work of the forces that wear away the rocky surface of the earth is shown by the present height of the Appalachian Mountains, which at one time were higher than the Rocky Mountains are today. These same forces have cut the Grand Canyon of the Colorado and produced the Bad Lands of South Dakota.

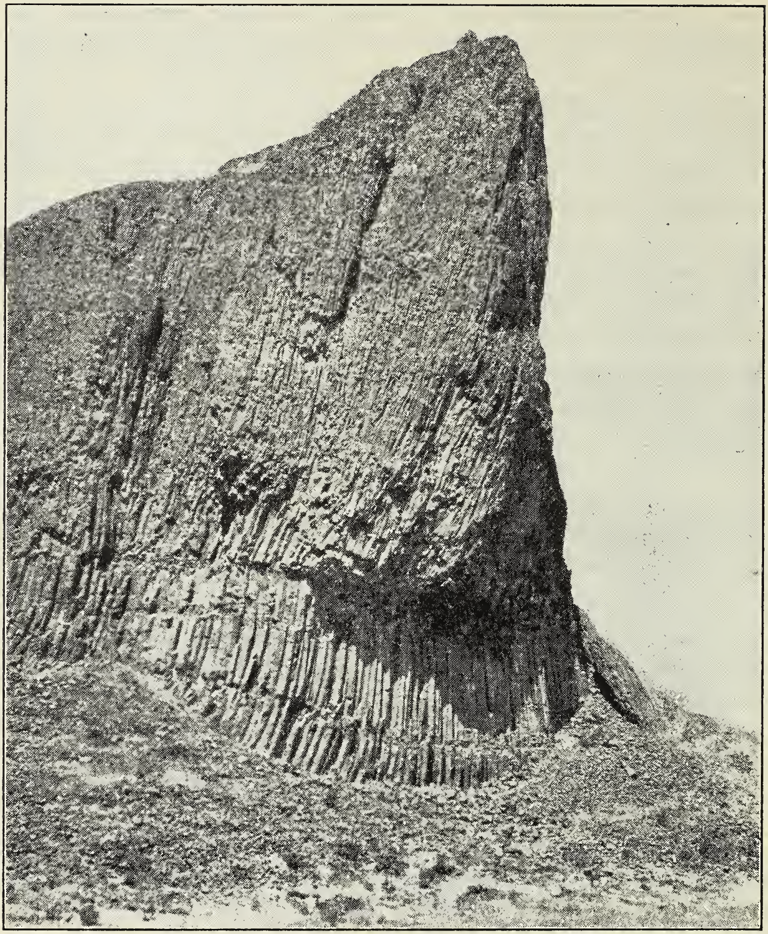
You should remember from your study of the history of the earth's crust that: (1) the earth is very, very old when compared with the recorded events of history such as the building of the pyramids or the discovery of America; (2) the rocky surface of the earth has been broken up into tiny rock particles by the action of heat, rain, rivers, winds, and waves; (3) there have been profound changes in the climate, not only of certain regions, but also of the earth as a whole; (4) all these changes on the earth are the result of natural forces; (5) these same forces are producing changes on the earth today; and (6) the forces shown by the action of heat, rain, rivers, wind, and waves are produced by energy from the sun.

PROBLEM: WHAT KINDS OF ROCKS FORM THE CRUST OF THE EARTH?

You have learned that there are three great classes of rocks: igneous, sedimentary, and metamorphic. In general, how were each of these formed? We shall now study each class of rocks in greater detail.

Experiment 58. To show that solids flow readily when melted. In a crucible heated by the blue flame of a Bunsen burner melt some solder or lead. Tip the crucible. Does the metal move in the crucible? Carefully pour some of the molten metal on to a piece of sheet iron. Does it flow readily over the iron? Does the metal solidify as it cools?

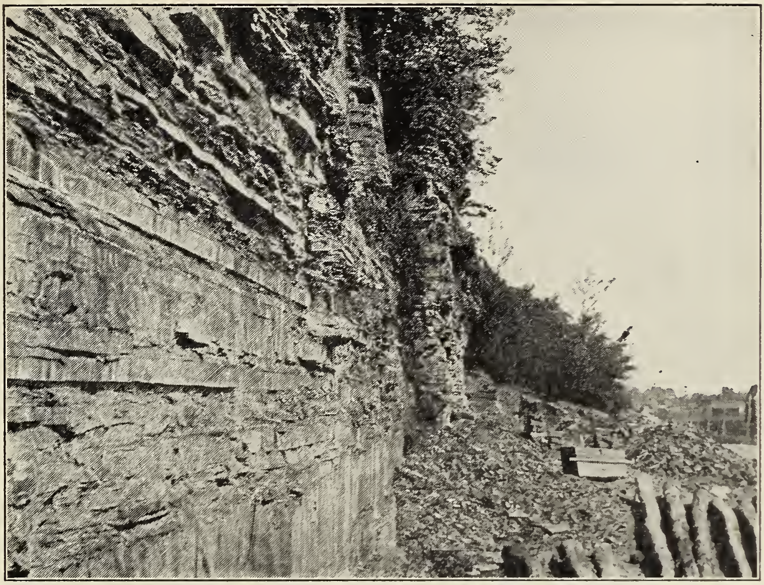
Igneous rock. Just as the weight of the air exerts a pressure upon the earth, so the weight of the crust of the earth and sea



Courtesy U. S. Geological Survey

FIG. 126. Igneous rock near Mesa, Washington. How is igneous rock formed?

exerts pressure upon its highly heated interior. In addition, the crust of the earth is cooling and consequently contracting. Sometimes these forces of contraction and compression are great enough to produce cracks or openings in the crust of the earth. Through these cracks, vast quantities of molten material are forced out. In some instances this material reaches the surface

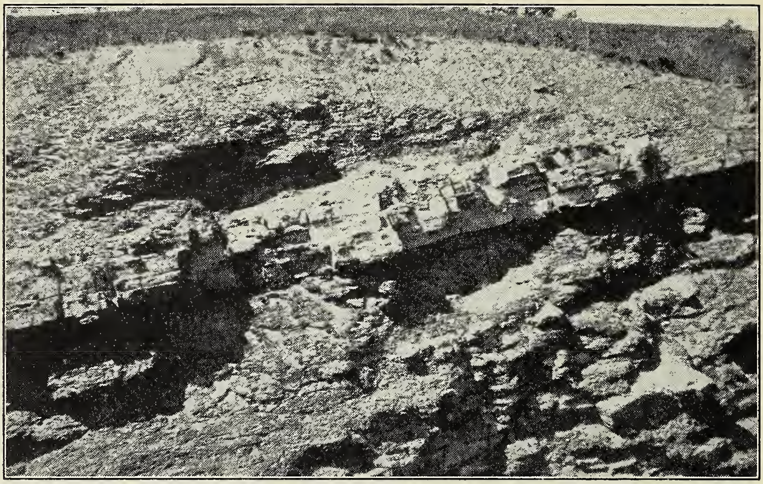


Courtesy U. S. Geological Survey

FIG. 127. Sedimentary rock, Watkins Glen, New York. How was this rock formed?

and is expelled with great force, as in a volcanic eruption. The molten material which is forced into the cracks does not always reach the surface, however, but may harden many feet below. In either case this material, when cooled and hardened, is called igneous rock (Fig. 126). The name comes from the Latin word *ignis,* meaning fire. Igneous rocks are usually massive, and in some cases where they are formed by a flow of lava from a volcano, they are found in layers. They can easily be identified because their appearance shows they have been melted and cooled. Igneous rocks contain few, if any, traces of fossils.

Experiment 59. To show how rock materials are deposited in water. Place enough soil in a jar of water to cover the bottom of the jar to a depth of about one inch. Shake the jar of soil and water and then let it stand until the water has cleared. With a magnifying glass examine the sediment in the jar. Where are the coarsest particles of soil? The finest particles? Why do you think they are so arranged?

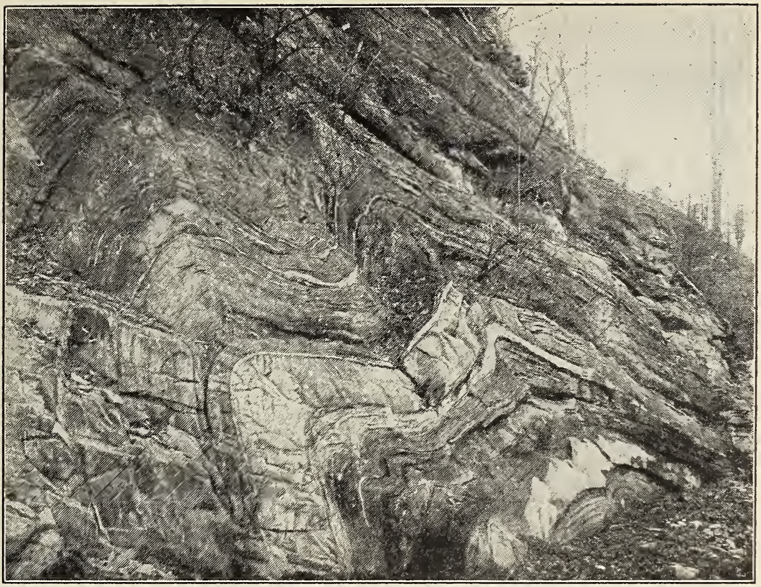


Courtesy U. S. Geological Survey

FIG. 128. What kind of sedimentary deposits become shale? Can you find rocks like these Virginia shales in your own locality?

Sedimentary rocks. In Experiment 59 you learned that the coarsest grains of sediment are deposited in a layer at the bottom, that above the bottom layer is a layer of finer grains and so on. Each layer is composed of particles more or less uniform in size. Should this sediment be formed by heat and pressure into rock, these layers would be called *strata.* We speak of rock formed in this manner as *stratified* rock, or sedimentary rock, because the materials were once carried as sediment in water and deposited in layers, or strata (Fig. 127).

For many ages rock-forming sediment has been carried by streams and rivers to the sea, where it has been deposited. As you might expect, the coarser particles were deposited near the shore, the less coarse particles a little farther away, and so on. Naturally the smallest particles were carried many miles from the shore before they came to rest on the floor of the ocean. Why? As years passed, this sediment became rock. The deposits of fine particles of sand became sandstone; the deposits of soft mud became shale (Fig. 128); shells and skeletons of various animals became limestone. As the layers of material piled



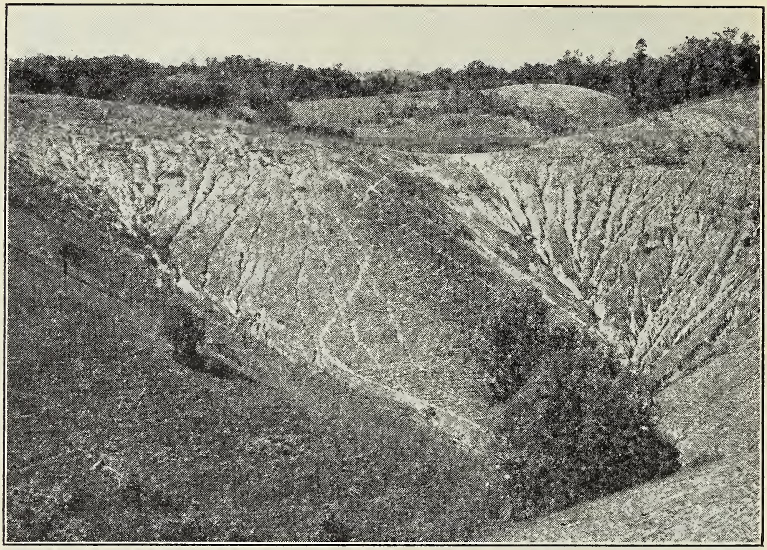
Courtesy U. S. Geological Survey

FIG. 129. Metamorphic limestone and dolomite in Vermont. What effects can you see of the intense heat and great pressure that this rock has undergone?

up, those at the bottom were hardened more and more by the additional pressure to which they were subjected. After sedimentary rocks were formed at the bottom of the sea, the great upheavals of the earth's crust lifted some of them above the surface of the water.

Other sedimentary deposits are chalk, salt, and coal. A *fossil* is the hardened remains of a plant or animal preserved in rock or merely a rock impression having the shape of a plant or animal. Fossils are often found in sedimentary rock.

Metamorphic rocks. In some cases, owing to the upheavals of the earth's crust, igneous and sedimentary rocks have been subjected to the forces of heat and pressure which have rearranged their mineral content and changed their structure. Rocks thus changed are known as metamorphic rocks (Fig. 129). The word metamorphic means "changed from one form to another."



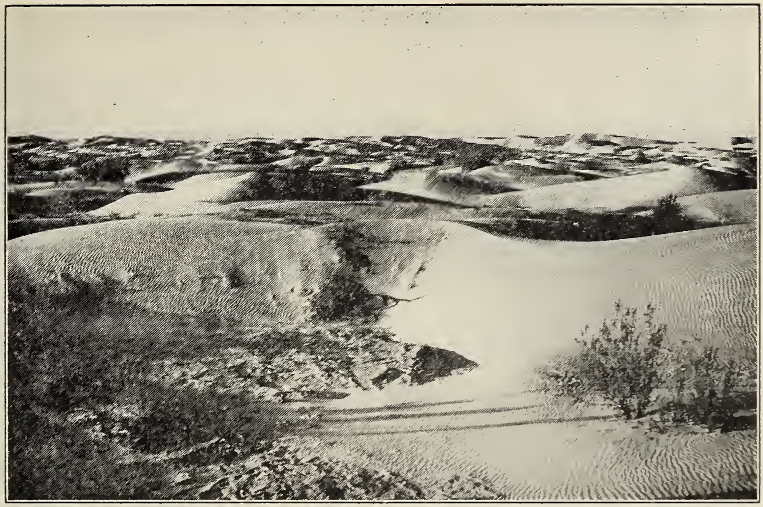
Courtesy Tennessee Valley Authority

FIG. 130. The wearing away of rocks and soil by water and wind is called erosion. Notice the gullys cut by water in the hillside on the right. Why are there no gullys in the grassy hillside on the extreme left?

Metamorphic rocks have a crystalline structure; they often contain crystals imbedded in them and sometimes bands of crystalline substances extending through them. Sedimentary rocks, when metamorphosed, become harder, denser, and more crystalline. Metamorphic rocks may have layers which split apart easily, as is the case with slate. Examples of metamorphosed igneous rocks are soapstone, and some kinds of slate; examples of metamorphosed sedimentary rocks are marble, most slates, and anthracite, commonly called hard coal.

PROBLEM: WHAT FORCES ARE CHANGING THE CRUST OF THE EARTH?

Weathering of rocks. As you know, the original rock materials of the earth's crust have been gradually broken up by the forces of nature (Fig. 130). The change in rock formation due to heat, rain, rivers, wind, and waves is known as *weathering.*



Courtesy U. S. Geological Survey

FIG. 131. The shape of sand dunes such as these near Amos, California, is always changing, because of the constant shifting of the sand by wind and rain. In stretches of sand near your home have you ever seen the patterns and ridges such as appear in the foreground above?

One kind of weathering is caused by the freezing of moisture which has found its way into the crevices and pores of rocks. When water freezes it expands; this expansion exerts a pressure of more than 2000 pounds per square inch. When freezing takes place in the crevices of rock, this pressure is exerted on the surrounding rock, forcing it apart.

Then, too, rocks expand when heated and contract when cooled, and these repeated expansions and contractions constitute another force which breaks rocks into smaller pieces. In mountainous regions and in other places where rocks are exposed to frequent and rapid temperature changes, it is easy to find great slabs of rock that have been broken or split off from larger rocks in this way.

Rain and wind remove small pieces from rocks and carry them from place to place (Fig. 131). Sometimes, wind laden with sand blows against rocks and wears them away. You have no doubt seen a stone building cleaned by using sand blown against the building by compressed air. In much the same way rocks are worn away by winds laden with sand.

Action of plants and animals in changing the crust of the earth. Plant and animal life exert powerful forces which help in breaking up rocks. Roots of trees and bushes twine around and through rocks, sometimes exerting enough pressure to break them apart. Have you ever seen a pavement broken by the pressure exerted by the roots of a tree? Plants known as lichens grow on the flat surfaces of rocks, and the chemical action accompanying their growth and decay causes portions of the rock to be dissolved, resulting in the gradual breaking up of the entire rock structure.

Earthworms, ants, gophers, ground squirrels, woodchucks, and other animals burrow into the soil and around rocks, making the movement of the soil and rock particles by wind and water easier and more effective.

As water filters or seeps through rocks and the decaying remains of plants and animals, it dissolves the acids and carbon dioxide in them. These substances greatly increase the power of water to dissolve mineral matter. Limestone, for example, is readily dissolved in water containing carbon dioxide. Even though only part of a rock is dissolved, the removal of this portion often causes the rest of the rock to crumble. Certain gases from volcanoes, when dissolved in water, form sulfuric acid, which aids further in the breaking up of rock material.

Action of glaciers in changing the earth's crust. Moving ice is another effective agency in breaking up rock and in transferring it from place to place. In mountainous regions where all of the snow does not melt even in summer, great rivers of ice form in the upper mountain valleys. These rivers of ice, known as *glaciers* (Fig. 132) move slowly down the valleys with a streamlike movement, swinging around curves, filling up cavities, and breaking up rocks in their paths.

A glacier flowing down a valley scrapes against the mountain slopes, removing whatever soil there is, breaking the rocks, and tearing away large boulders. The rocks and stones carried along by the glacier increase its effectiveness in grinding other rocks.

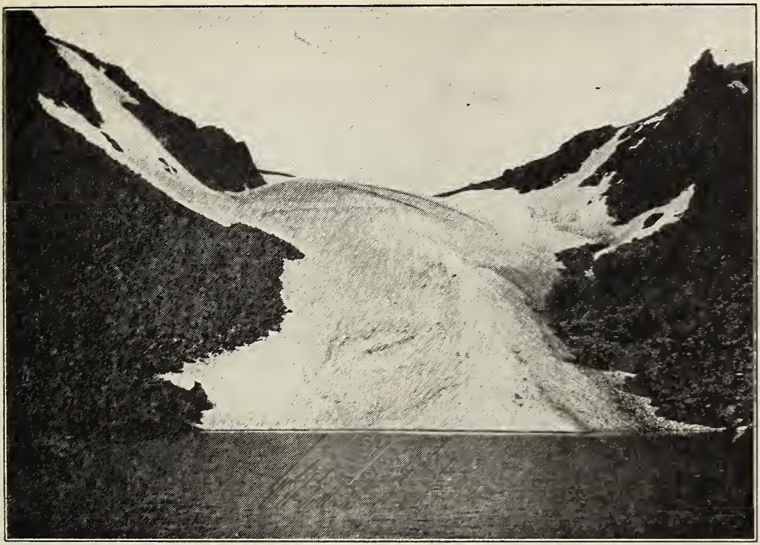


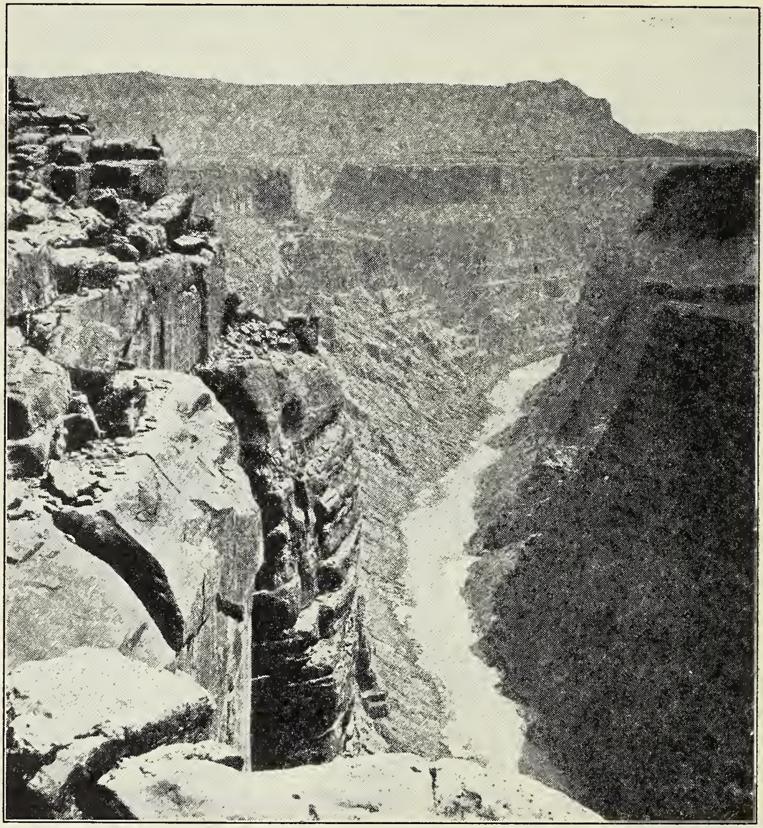
Photo by W. T. Lee *Courtesy National Park Service*

FIG. 132. Andrews Glacier, in the Rocky Mountains. In what ways does a glacier help to change the earth's crust?

Rock material was once carried in this way from the far north for thousands of miles southward across North America. Was the section of the country in which you live ever covered by a glacier?

Glaciers move very slowly. In 1827 a man named Hugi decided to find out the rate at which a glacier moves. He built a small hut on a glacier and marked its exact location with reference to the mountain side. Three years later he found the hut had been moved 330 feet; at the end of six years it had traveled 2340 feet; and by 1841, nearly a mile. Some glaciers move more rapidly; the Muir Glacier in Alaska at its outlet to the sea moves several feet a day.

Action of water in changing the earth's crust. You have learned some of the ways in which rocks are broken up into small rock particles. What part does water play in this process of weathering? What part does water play in carrying rock particles from place to place?



Courtesy U. S. Geological Survey

FIG. 133. Grand Canyon, Arizona. Why are the walls so steep? Why are they not worn down (eroded) like the banks of other rivers no older than the Colorado? You can estimate roughly the depth of the canyon by comparing it with the height of the man in the upper left.

When rain falls on the earth, the water may evaporate; it may sink into the soil; or it may flow along the surface of the ground. As water flows along the surface of the ground it wears gullies into the soil and may even cut deep river beds and canyons. This wearing away of rocks and soils and the cutting of gullies and river beds by the action of water is called *erosion*. The Colorado River is a good example of one which has greatly changed the surface of the earth (Fig. 133). This river flows hundreds of miles through canyons which vary in depth from a few hundred feet to several thousand feet. Because of limited rainfall in the region through which it flows, this river has cut its bed much faster than the adjacent land has worn away; and instead of a wide valley, such as is formed by rivers which flow through regions of moderate or heavy rainfall, it has cut the deep gorge in Arizona called the Grand Canyon of the Colorado.

Is weathering going on today? You see now how weathering and erosion have been going on since the beginning of the formation of the earth's crust. Large rocks have been ground into small rock particles, and these have been carried from place to place by wind, water, and ice. Mountain slopes have been worn away and rivers with swift currents have carried the rock particles down into the valleys, depositing them on flood plains and in deltas. Slowly through the ages this wearing-away process has been going on, the deep valleys have been partly filled, and uneven surfaces have been covered with a mantle of rock material to form level plains.

The processes of weathering and erosion are still going on today as they have in the past. Observations of a swift stream or steep hillside will show evidence of these processes. In the next chapter we shall learn what other materials must be added to rock particles to make them into fertile soil in which plants grow.

Springs and artesian wells. Part of the water that sinks into the soil finds its way into underground streams, flowing above a layer of hard rock through which water cannot pass. Should this layer of hard rock lead to a point at the surface of the earth, a *spring* may be formed (Fig. 134). If a hole is bored through soil and rock until such an underground stream is reached, an excellent supply of fresh water may be found.

If the formation of the rocks is like that shown in Figure 135, a deep-bored well, known as an *artesian well*, can be sunk, from which water will flow without the aid of a pump. Why? Probably the most famous artesian well is at Grenelle near Paris. It is 1740 feet deep and delivers more than 500 gallons of water a minute at a temperature of 84° F. One of the deepest artesian wells in the world (4200 feet) is near Berlin. Near Kissingen, Germany, is an artesian well 1800 feet deep which throws a stream of water 58 feet into the air. A large number of artesian wells have been bored in the United States. Are there any natural springs in your locality? Are there any artesian wells?

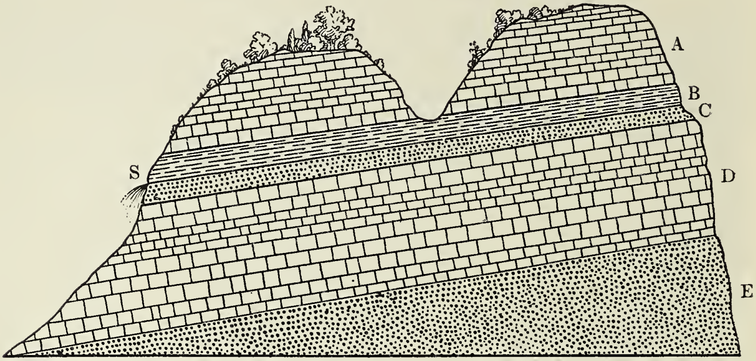


FIG. 134. When you find a spring, you may expect rock formation somewhat like this. *A*, limestone; *B*, shale; *C*, coarse sandstone; *D*, limestone; *E*, sandstone; *S*, spring. At what other places on the diagram might springs be formed?

How are natural caves formed? When water containing carbon dioxide flows underground through limestone rock, it slowly dissolves the limestone and carries it away in solution. The continued removal of the limestone soon leaves an opening in the rock, which forms the beginning of an underground cave. The cave may be enlarged by this process to a considerable size. As water trickles through the porous limestone it carries tiny quantities of the limestone in solution. The continued dripping of

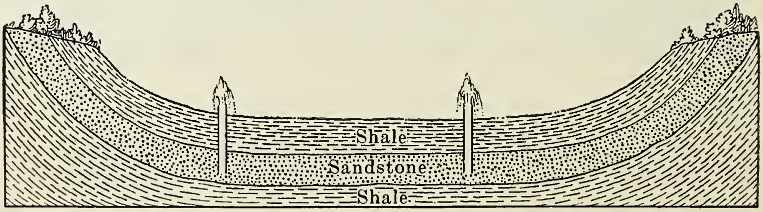
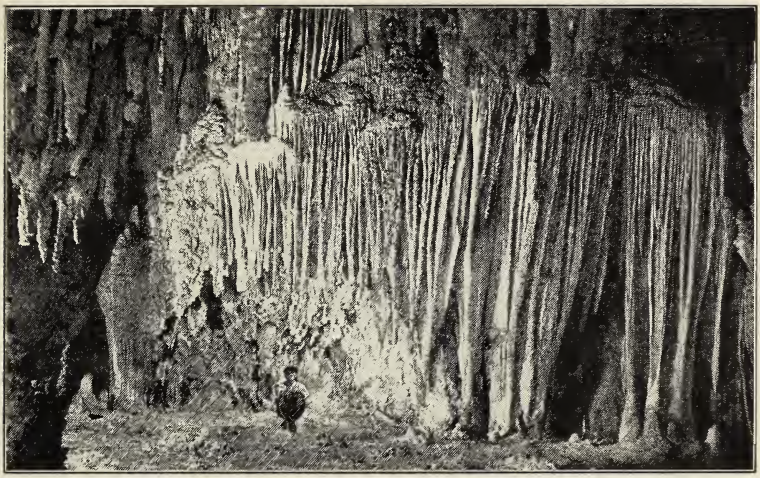


FIG. 135. Diagram of artesian basin, showing arrangement of rock strata.



Courtesy U. S. Geological Survey

FIG. 136. The work of underground waters: stalactites and stalagmites in Carlsbad Cavern, New Mexico.

this solution from the roof of the cave and evaporation of the solvent leaves a deposit of limestone, shaped like an icicle, called a *stalactite.* As drops of the solution fall upon the floor of the cave, they also deposit bits of limestone, until a *stalagmite* is formed. Generally it is thicker than a stalactite. The stalagmites slowly grow upward, finally meeting the stalactites hanging from the roof of the cavern, thus forming pillars in the cave (Fig. 136). This work of underground water has created marvelous formations in many caves throughout the world.

Caves are also extremely interesting because they have often been found to contain fossils and other remains of animals, from which we may learn something of the history of the earth. Among the earliest caves to be studied in a scientific way were those in Franconia, Germany, where beneath stalagmite floors have been discovered bones and teeth of such animals as the lion, hyena, grizzly bear, and reindeer—animals that have long since ceased to exist in this region. Relics found in certain caves have also yielded considerable knowledge concerning primitive man. Rough implements of flint, bone arrow heads, and other products of

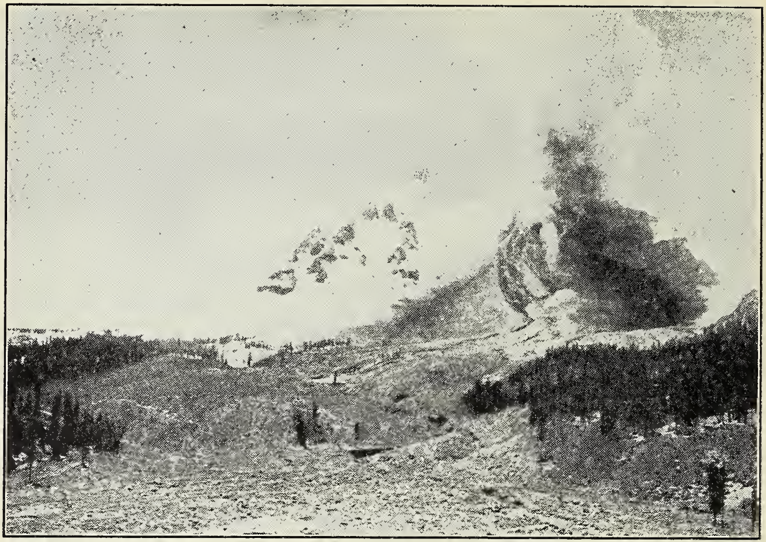


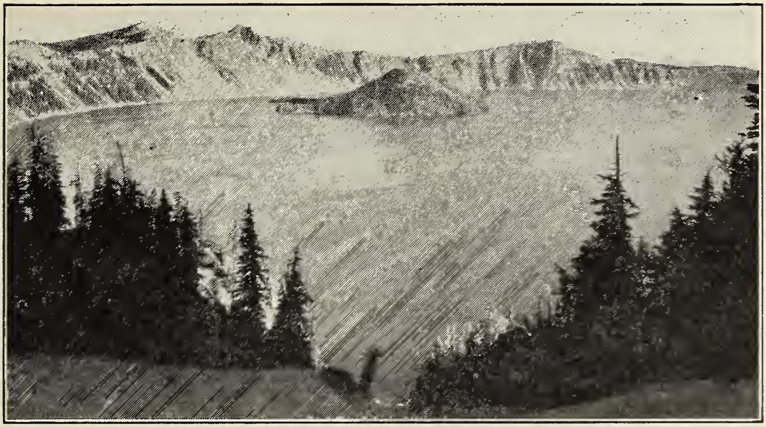
Photo by B. F. Loomis *Courtesy National Park Service*

FIG. 137. Lassen Peak in eruption. The area in northern California in which this volcano is located, is now Lassen Volcanic National Park.

prehistoric man's skill show something of the progress of early civilization. In Spain, paintings of animals, some in color, have been found on the walls of caves.

The largest and most accessible cave of all is the famous Mammoth Cave in Kentucky, with its system of rivers and lakes, its network of galleries and passages, and its majestic stalactites and stalagmites. The length of this cave is estimated to be one hundred fifty miles. It has also been estimated that, to form this cave, no less than twelve million cubic yards of material have been dissolved and carried away by the action of underground water. Skeletons of an unknown race of men have been discovered under the layers of limestone, giving rise to the belief that the cave was at one time used as a home by savage tribes.

Volcanoes. As we stated earlier in this chapter, the interior of the earth is believed to be a heated mass under tremendous pressure. Whenever this pressure becomes sufficiently great to force the heated material to the surface of the earth, a *volcano* is formed



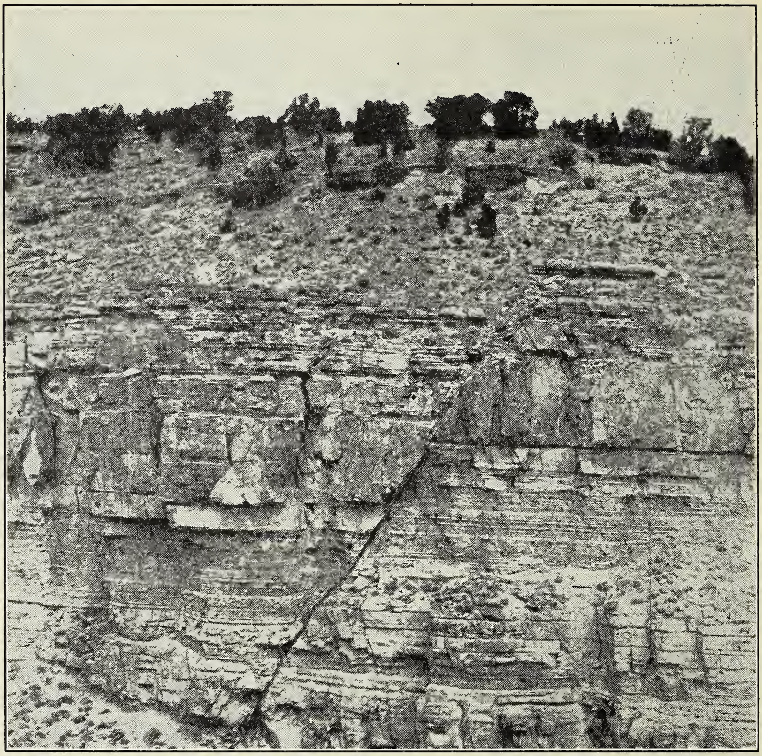
Courtesy U. S. Dept. of the Interior

FIG. 138. Crater Lake, National Park. This lake was formed by water filling the crater of an extinct volcano.

(Fig. 137). The material brought to the surface usually forms a hollowed out cone-shaped hill and in time a volcanic mountain.

The cup-like top is called the *crater*, from a Latin word meaning a bowl. Volcanoes in eruption are spoken of as *active volcanoes.* Old volcanoes which have never been known to erupt are said to be *extinct.* A volcano that for centuries has been considered extinct, may become active again. Do you know of an extinct volcano which has become active?

The volcanic mountain Vesuvius had been quiet for so long a period that people living near the mountain had no fear of an eruption. About 63 A.D. earthquake rumblings were heard; these were repeated from time to time, but the people became accustomed to them and paid little heed to their warnings. Finally, in 79 A.D., a great cloud of black smoke arose from the crater, filling the air with dust and ashes. Rocks and stones rained on the mountain side. It is said that lightning flashed and thunder rumbled. Even the sea was lashed to great fury. The eruption lasted for about two days, and when it had ended, the material thrown out had buried three cities, Herculaneum, Pompeii, and Stabiae.

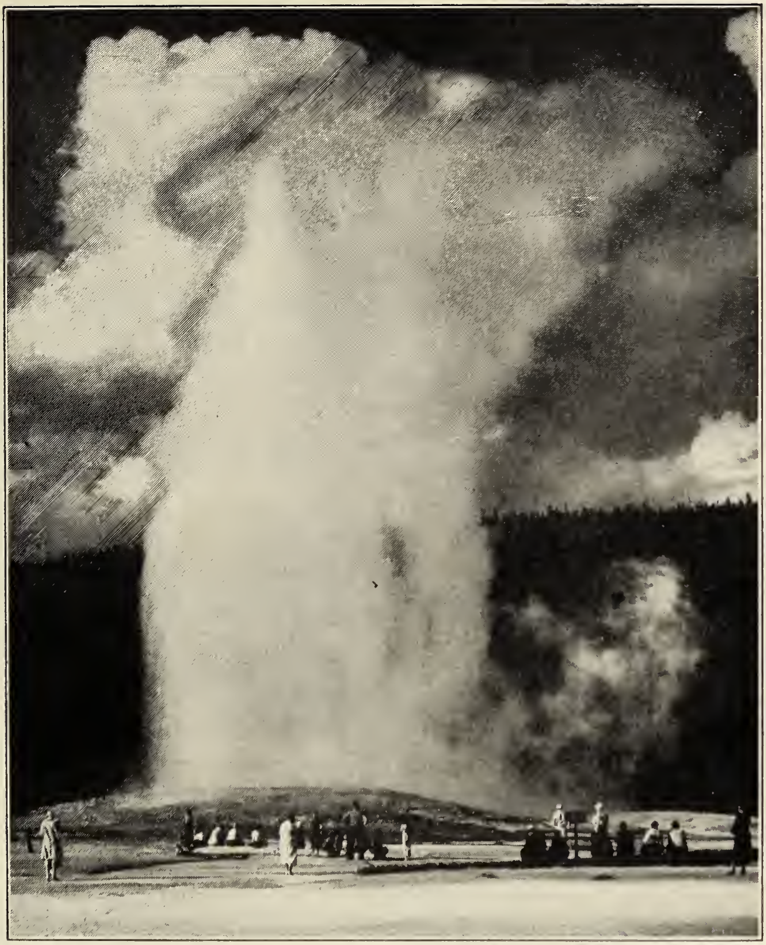


Courtesy U. S. Geological Survey

FIG. 139. A fault in sandstone rock near White River, Colorado. Notice that the layers of rock on the left have slipped several feet below the level of the corresponding layers on the right.

What causes earthquakes? The crust of the earth is in a state of continual trembling. Many of these tremblings are very slight and are confined to a very small area. They are caused by such things as the beating of the ocean waves on the shore, heavy traffic on the streets, and the blasts of powder in mines and the like. Some tremblings, however, are so severe that the earth's crust is violently shaken over large areas. Such a trembling of the crust of the earth is called an *earthquake.*

One of the common causes of earthquakes is the breaking of rock strata of the earth's crust. When this happens, the rock on



Courtesy U. S. Dept. of the Interior

FIG. 140. Old Faithful Geyser, in Yellowstone National Park, erupting. Probably you have heard stories from tourists of how eggs are cooked in the hot water of this geyser.

one or both sides of the break "slips" down, resulting in what is called a *fault* (Fig. 139). The slipping of the rock formation causes the earthquake. A violent eruption of a volcano often causes earth tremors of sufficient intensity to be observed hundreds of miles from their source. A cause of minor earthquakes is the force of the impact of a great landslide or avalanche when it strikes the land at the base of a mountain. The collapsing of the roof of an underground cave or cavern produces an earthquake of slight intensity.

The most violent and the greatest number of earthquakes occur in the lands bordering the shores of the Pacific and Indian oceans. These tremblings though thousands of miles away are registered by an instrument called a *seismograph.*

Geysers. In volcanic regions and places where molten material from the interior of the earth has been thrust comparatively near the surface, water may find its way down through soil and porous rock to a point where the rocks are still hot. If water heated by contact with these rocks is forced to the surface, a hot spring is formed. The temperature of the water may vary from 60° F. to boiling temperature. If the channel leading to the surface is narrow and deep, the water in it cannot circulate readily and the pressure at the lower part of the channel is greatly increased because of the weight of the water above. It requires a higher temperature to boil water when the pressure is higher than normal air pressure (page 368). Consequently, at the bottom of some of these underground channels, the boiling point of water is thought to be as high as 257° F. When the water does boil, it is changed to steam and its volume is greatly increased. This expansion of water changing to steam forces great quantities of water and steam high into the air. Such an eruption is called a *geyser* (Fig. 140).

Geysers are found in New Zealand, in Iceland and in our own Yellowstone Park. One of the most famous in Yellowstone Park is "Old Faithful," which throws a stream of water and steam to a height of from 125 to 150 feet about every sixty minutes. After each eruption the water in the bowl of the geyser remains comparatively quiet until an accumulation of steam forces another eruption. The water of geysers brings up many mineral substances in solution and deposits them around the crater, sometimes building up a cone similar in shape to that of a volcano. Geysers are symptoms of the approaching end of volcanic activity.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

artesian
brontosaurus
crater
crust
diplodocus
earthquake
erosion
eruption
fault
fossil
geyser
glacier
igneous
limestone
metamorphic
sedimentary
seismograph
stalactite
stalagmite
strata
stratified
upheaval
volcano
weathering

Write the number of each item on your paper and after it the word that completes the statement.

1. Heated material from the interior of the earth that has solidified is known as __________ rock.

2. Sandstone is an example of __________ rock.

3. Hardened remains of plant and animal life or their impressions are called __________.

4. Changes in rocks due to heat, rain, and wind are known as __________.

5. The source of the energy for tearing down mountains and crumbling rock is the __________.

6. The cup-like top of a volcano is called __________.

7. The dislocation caused by slipping rock strata is called __________.

Which item in each of the following lists does not belong with the others?

8. cave; stalactite; stalagmite; limestone; wind.

9. pressure; fossil; plant; glacier; rock.

10. marble; soapstone; metamorphic; sedimentary; heat.

Which of these statements are true? If any are false, re-state them in correct form.

11. Metamorphic rock is stratified.

12. Natural caves are formed by the wind.

13. A spring and an artesian well are the same.

14. The changes in the earth's crust have been made by natural forces.

15. The climate of Greenland has always been very cold.

CHAPTER XIV

WHAT IS SOIL AND HOW DOES MAN PREPARE IT FOR GROWING USEFUL PLANTS?

Do you know:

That earthworms play an important part in making soil and in keeping it fit for plant growth? The difference between clay soil and loam? That there must be air and water in soil if plants are to grow? How soil is formed?

What weeds are? What plants use for food? Why drainage is necessary to make some soils productive? What is meant by dry farming? That a farmer should plan the diet for his crops carefully?

PROBLEM: WHAT IS AGRICULTURAL SOIL AND WHY IS CULTIVATION NECESSARY?

We have been studying the natural forces which, working together, grind rock into rock particles. Our problem now is to learn what has been added to rock particles to form soil, and how man prepares soil in order to raise useful plants.

Experiment 60. To find out what soil is made of. Examine a small quantity of agricultural soil under a low powered microscope or a magnifying glass. What two kinds of particles do you see? What do you think these particles are?

The materials that under the microscope seem to be small stones and fine black particles are nothing more than tiny bits of rock and decayed organic matter. The tiny rock particles may have been carried from places thousands of miles away to the spot where you found them. If they were transported through a region of heavy rainfall, probably the chief carrier was water; if through a region of little rainfall, probably the chief carrier was wind. Glaciers too have transported great quantities of rock particles long distances. The black particles are bits of plant and animal life in various stages of decay. As plants and animals have died, their remains have become mixed with the rock particles by wind, water, the burrowing of animals, and in other ways.

Burrowing animals not only aid in making soil but also assist in keeping it from becoming hard and packed. The tiny holes made in the soil by earthworms and other animals loosen the soil and permit air and water to pass through easily. Air and water must be present in soil if plants are to grow.

In a soil suitable for agriculture there are also living organisms—plants called bacteria (page 509)—so small that they cannot be seen without a microscope. They, too, play a very important part in making soil productive. These tiny plants aid in the decay of organic matter and in the changing of plant food into a form that can be absorbed by the roots of plants. In most soils, each soil particle is surrounded by a very thin layer (film) of water in which these bacteria live.

Soil, then, is a general term given to weathered rock in which there are varying amounts of other materials. An agricultural soil—soil suitable for growing useful plants—is composed of (1) rock particles, (2) soil water, (3) soil air, (4) decaying organic matter, and (5) living organisms (bacteria).

How are soils classified? A soil is classified according to the size of its rock particles.

Kinds of soil	*Diameter of particles*		
Fine gravel	2	to	1 mm.
Coarse sand	1	to	0.5 mm.
Medium sand	0.5	to	0.25 mm.
Fine sand	0.25	to	0.10 mm.
Very fine sand	0.10	to	0.05 mm.
Silt	0.05	to	0.005 mm.
Clay	0.005		or less

About what is the diameter of a particle of clay? Of silt? Soils with medium-sized particles ranging from very fine to coarse sand are called *sandy soils*. Soil with very fine particles is called *clay* or *silt*. Coarser particles are called *fine gravel* or gravel. *Loam* is a mixture of sand and clay rich in organic matter. Soils are sometimes named after a region in which they are common.

Thus we have Norfolk sand, one of the common soils of the Atlantic flood plain; Miami silt loam (named for the Miami River in Ohio), widely distributed throughout the corn belt in the Middle West; and Wabash clay, found in the Wabash River valley and in many others of the Mississippi River system. What is the name of the most widely distributed soil in your locality?

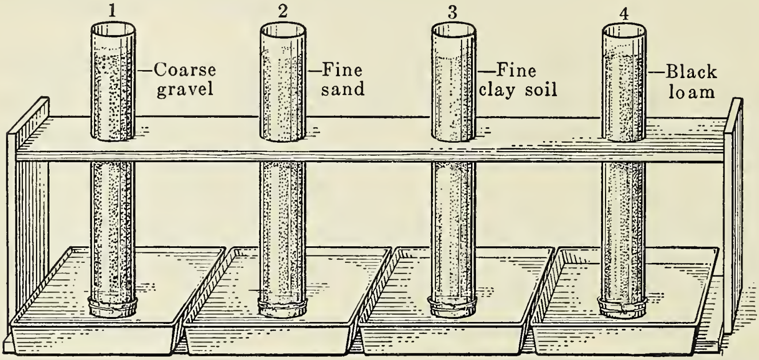


Fig. 141. An experiment to test the capacity of different kinds of soils for holding water.

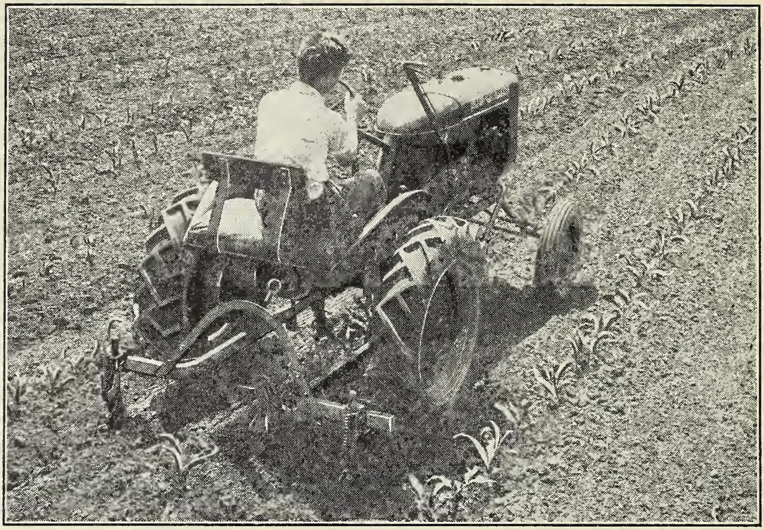
Experiment 61. To show that certain soils hold more water than others. Arrange several lamp chimneys or large open tubes as shown in Figure 141, and put into each a different kind of soil. Fill each chimney to the same height. Pour the same volume of water into each chimney. After allowing the tubes to stand for an hour, measure the volume of water that has passed through each. What do the results of this experiment show? Beginning with the one that holds the most, list the soils in the order of their capacity to hold water.

How is the amount of water in soil dependent upon the size of its soil particles? The size of soil particles, as you saw in Experiment 61, determines the amount of water that a soil can hold. Clay soil, for example, holds more water than sandy soil. Except in very dry climates a film of moisture surrounds each soil particle. This moisture is called *soil water*. The finer the particles, the greater the amount of soil water in a given volume of soil, since the total surface of the small particles will be greater than that of larger particles.

This fact may be illustrated rather roughly by considering a cubic foot of wood made up of 1728 smaller blocks of wood, each with a volume of one cubic inch and a surface area of 6 square inches. These 1728 small blocks will have a total surface area of 10,368 square inches; whereas, if the cubic foot of wood were a solid block, it would have a surface area of only 864 square inches. Therefore the greater surface afforded by a given volume of very small soil particles provides a much larger area for attracting and holding soil water than does the surface afforded by the same volume of larger particles. The size of the soil particles is, therefore, an important factor in the productivity of soil, because soil water is necessary for the growth of plants.

Although the fineness of the soil particles of clay gives it great capacity for holding soil water, this very quality may prevent it from being a good agricultural soil. In the first place, when planting time comes in the spring, more moisture must be evaporated from it than sandy soil. You know that the sun's rays do not warm water as quickly as they warm soil, and, furthermore, that the evaporation of soil water has a cooling effect on the soil. Consequently, clay soil remains cold and wet in the spring longer than nearby sandy soil. As a result, crops cannot be planted in clay soil as early as in sandy soil; and even after they are planted, the growth of certain plants is slow owing to the coldness of the clay soil. In springtime you may have noticed that in a region having sandy soil lawns become green earlier than in an adjacent region having clay soil, although the weather may be about the same in both.

The need for cultivation of the soil. If a garden or field is planted and left for some time without cultivation, many undesirable plants called *weeds* come up along with the crop. Weeds are very hardy and difficult to kill. For example, in the struggle to live some of them, such as dock, dandelion, and ragweed, have developed roots that go down deep in the soil, while others have widely branching roots that spread far underground. Some, like plantain, have developed broad leaves that prevent other plants near them from getting sunlight, thereby killing them. Weeds not only use up plant food in the soil, but in some instances



Courtesy Allis Chalmers

FIG. 142. To loosen the soil around the roots of plants and to keep down weeds between rows of cultivated plants, tractors are used on many farms.

they actually render the ground poisonous to useful plants. To free the soil from certain weeds, it is necessary to dig them out by the roots. Others can be killed by frequent cultivation of the soil.

Certain soils, especially heavy clays, that have not been cultivated for some time, have a tendency to become hard and lumpy as they dry out. If lumps or clods rest on seeds and tender plants, they retard, and may even prevent, the growth of crops. Furthermore, unless these clods are broken up, they greatly reduce the capacity of the soil to hold air and moisture, both of which are necessary to plant growth. The process of breaking up clods and loosening the soil around the roots of plants is called *cultivation* (Fig. 142). In a wider sense cultivation also includes: (1) the addition of manure and other fertilizers to soil to increase its supply of plant food and (2) the preparation of soil for planting.

Since soil water is necessary in agricultural soils, it should be conserved, especially in times of drought. If soil planted to crops is kept loose and comparatively free from clods by cultivation, it will absorb large quantities of rain and thus store up a supply of soil water beneath the surface. Unless soil is cultivated, it tends to become hard. The advantages of soil cultivation can be seen readily if one of two adjacent fields of corn or other crop is cultivated and the other is not. The plants in the cultivated field even in dry weather will look fresher and greener than the plants in the other. When it rains on the uncultivated field much of the water flows away. A well-cultivated field absorbs water readily and keeps it available for plant growth. In an uncultivated field weeds will grow and remove water from the soil.

PROBLEM: HOW IS THE AMOUNT OF SOIL WATER REGULATED?

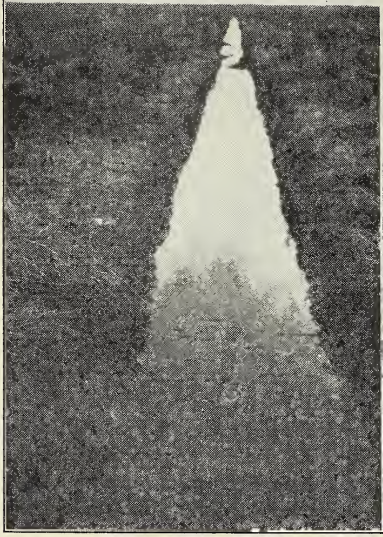
In certain regions, owing to heavy rainfall, there may be a surplus of soil water; while in other regions, owing to scanty rainfall, there may be an insufficient supply of soil water. A lack of soil water may be remedied by *irrigation,* described on page 234. Where there is a surplus of water, the excess may be removed by *drainage.*

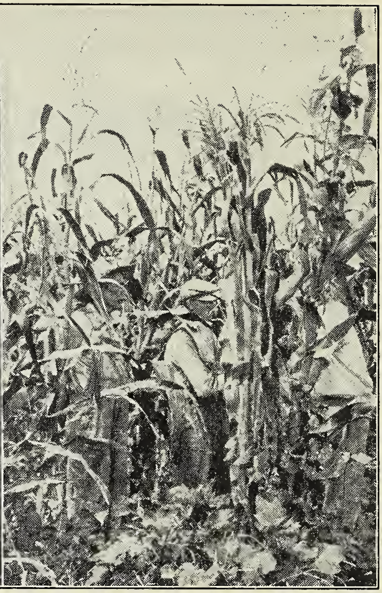
Drainage of wet soils. A surplus of soil water may flow into surface streams and rivers, or into underground streams, and thus be removed by natural drainage; e.g., the Mississippi River with its branches is a great natural drainage system. Artificial drainage for agricultural purposes may be accomplished by digging open ditches or by providing an underground system of porous tiles.

The open ditch has one advantage, that of low initial cost; however, its disadvantages are serious. An open ditch soon becomes partially filled with sediment and debris; it often involves a waste of good land; and it may interfere with cultivation and harvesting. Why?

A system of underground drainage by means of porous tile provides by far the best artificial drainage. If such a system is properly laid, it will last for years.

Large artificial drainage systems in the Everglades of Florida, the Great Dismal Swamp of Virginia and North Carolina (Figs. 143 and 144), and cypress swamps in the southern part of the





Courtesy N. C. State College of Agriculture and Engineering

Fig. 143. A drainage ditch through swamp land in North Carolina.

Fig. 144. Corn on reclaimed swamp land in North Carolina.

From Figs. 143 and 144, does it seem to you that the draining of this land is worth while?

United States have made it possible to cultivate thousands of acres of fertile land which is now highly productive. The United States Geological Survey estimates that there are still in our country more than 100,000,000 acres of swamp lands, much of which could be drained and used for agricultural purposes.

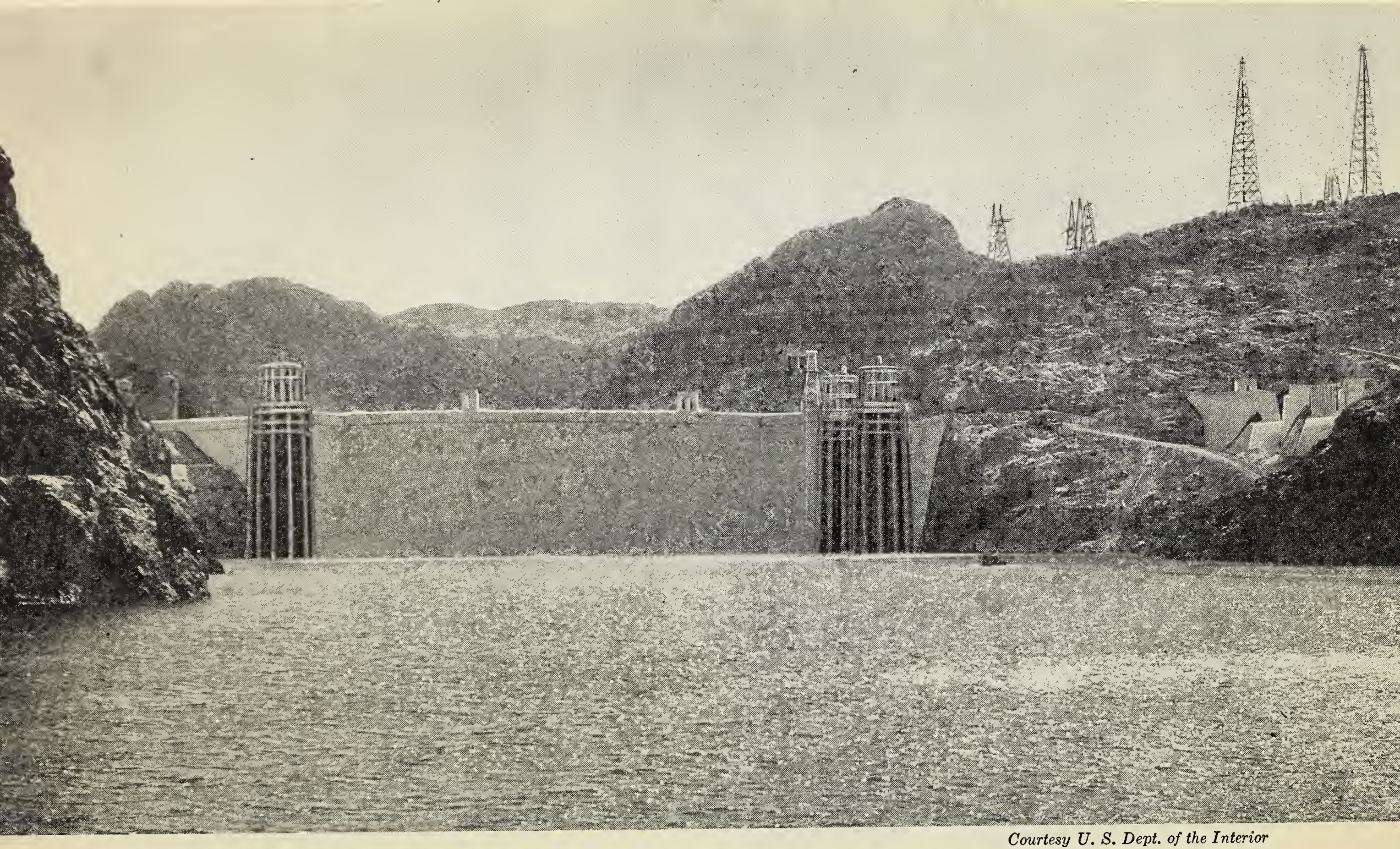
Irrigation. In certain parts of the world the annual rainfall is so small or is confined to such short times of the year that the soil water is insufficient for the growth of crops. Often this land is fertile, and the climate is such that the soil would be capable of producing excellent crops provided there were enough soil water to enable plants to secure food from the soil.

Irrigation is the supplying of water to land by artificial means. In some places a water supply is secured by digging ditches which carry water from nearby rivers or lakes to the fields. In other places water may be obtained by constructing a reservoir, which may be filled with water by damming or changing the course of rivers or mountain streams. Some of the greatest dams in the world have been constructed partly for irrigation purposes. Water may be carried through tunnels in the mountains or through elevated aqueducts over valleys to the places where it is to be used. In some places, the reservoir is filled by water pumped from deep wells.

From such reservoirs, water may be conducted by a canal to the land to be irrigated. The smaller canals that branch from the main canal subdivide into still smaller branches, which bring water to the fields. In a well-managed irrigation project careful records are kept over a period of years of the measurements of the volume of water that flows through the canals, the amount of rainfall, the kinds and value of crops raised, the increase in land values, and other items essential to the financial success of the project.

The advantages of irrigation were known to the ancient Egyptians in the Nile Valley. During the flood season the Nile River overflows its banks, covering the valley with a fertile deposit of mud. When the river returns to its banks the inhabitants hasten to sow their crops. Rice, oats, barley, and wheat grew in abundance on the land fertilized by the river deposits, making Egypt the granary of the ancient world. But since this natural overflow of the Nile occurs but once a year, only one crop a year can be raised; the soil then lies idle until after another flood, unless water is supplied by artificial means. Ancient Egyptian carvings show slaves carrying water to their masters' gardens. But more effective methods than this were employed in the early history of Egypt; water was drawn from wells and reservoirs by a device operated by the aid of oxen, and then conducted by ditches to gardens and fields for the growing crops.

Agriculture also flourished in the arid country around the ancient cities of Babylon and Nineveh in Mesopotamia, because the land was irrigated by water from the Tigris and Euphrates rivers. Today most of this region is a desert.



Courtesy U. S. Dept. of the Interior

FIG. 145. Boulder Dam, the highest dam in the world, makes possible Lake Meade which is the world's largest artificial reservoir. The water is used mainly for irrigation purposes and for the generation of electric power.

In the United States irrigation has been made possible in a number of regions through the work of the United States Reclamation Service under the direction of the Department of the Interior. One of the great projects of the Reclamation Service is the Boulder Dam which is located in Black Canyon of the Colorado River. It is 727 feet high and holds back water forming a reservoir (Lake Mead) with a capacity of 30,500,000 acre feet. An *acre foot* is the amount of water needed to cover one acre of land to a depth of one foot.

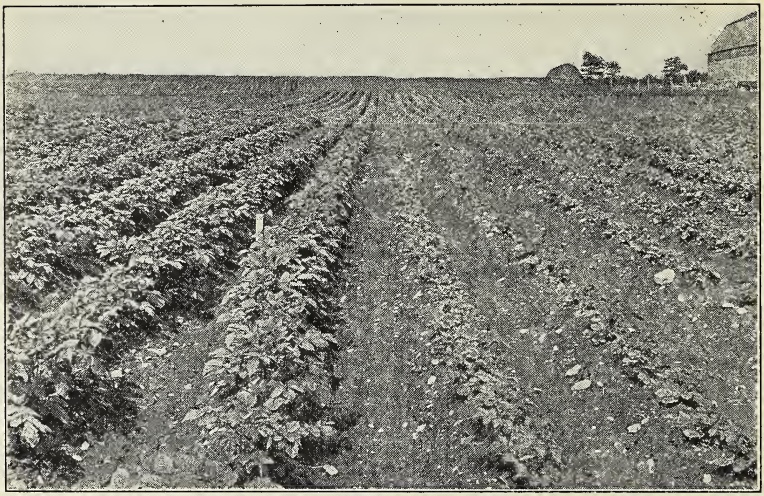
Problem: What Is Meant by Soil Conservation and Why Is It Necessary?

Plants as well as animals require food for growth. The foods which plants use come from the soil and the air. The chemical examination of many different vegetables and cereals shows that they are composed chiefly of the following elements:

Carbon
Hydrogen
Oxygen
Nitrogen
Sulfur
Phosphorus
Calcium
Potassium
Magnesium
Sodium
Iron
Chlorine

For a detailed study of these elements see page 256. All of them are found in the soil and, with the exception of carbon and oxygen, the plant can obtain them from no other source. We conclude, then, that they are taken from the soil by the plant roots. Carbon, hydrogen, and oxygen are combined in the leaves of plants to produce plant foods known as *carbohydrates*—sugars and starches. Plants contain some iron also. Although sodium and chlorine are present in all plants, their function in plant growth is not known at the present time. Sulfur is found in all growing parts of plants and also in certain of the foods (*proteins*) produced by plants. Magnesium seems to have something to do with the formation, growth, and ripening of seeds.

What plant foods must be supplied? Of the twelve elements of which plants are chiefly composed, only four—nitrogen, phosphorus, potassium, and calcium—must be added to agricultural soil to maintain its productivity. A supply of these elements is necessary because successive crops need larger amounts of them



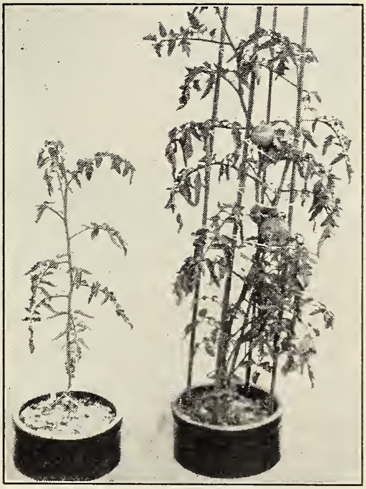
Courtesy U. S. Dept. of Agriculture

FIG. 146. The potato plants on the left received fertilizer containing the plant food that was lacking in the soil. The fertilizer supplied to the rows of potatoes on the right lacked certain compounds necessary for the growth of potato plants.

than most soils contain. These four elements may not all be lacking in a given soil; however, a soil is poor if it lacks any one of them. Materials which are put into the soil to furnish these four elements are called *fertilizers*. Study Figures 146 and 147.

Nitrogen compounds as plant foods. Nitrogen is one of the elements, then, that must be added to certain soils to make them productive. United with carbon, hydrogen, and oxygen, it forms a part of proteins, which are needed to build *protoplasm*, the living substance of all plants and animals (page 508). Consequently, nitrogen is found in almost every part of plants and animals. As such plants as wheat, rye, oats, and grass remove large quantities of nitrogen from the soil, compounds containing nitrogen must be returned to this soil if it is to continue to be productive.

The commercial fertilizers which contain nitrogen usually contain one of these substances: sodium nitrate, ammonium sulfate, potassium nitrate, or a mixture called cyanamide. Cyanamide, a manufactured product, gets its nitrogen from the vast storehouse of free nitrogen in the air. Ammonium sulfate is a by-product (a product obtained in addition to the main product) in making coke from coal. Quite recently potassium nitrate has been discovered in Northwest Texas. It is mined also in quantities in Strassfurt, Germany, and in France. Sodium nitrate is found extensively in nature, and large quantities of it are used as fertilizer. There are small deposits in California and Nevada, but most of the sodium nitrate used in the United States has come in the past from Chile. It contains about sixteen per cent of nitrogen.



Courtesy U. S. Dept. of Agriculture

FIG. 147. From these two plants, one of which was fertilized, do you think it might pay a farmer to fertilize his crops?

Certain organic matter, such as barnyard manure, dried blood and other slaughter house refuse, fish waste, cotton seed from which oil has been extracted, and linseed meal (flaxseed from which linseed oil has been extracted), contains nitrogen and is therefore used as fertilizer. In fact, these organic compounds are much better fertilizers than the nitrate compounds. Bacteria which bring about decay change the nitrogen in barnyard manure and other organic substances into nitrates by a very slow process, making it possible for growing plants to use the nitrogen in these substances as fast as it is available. On the other hand compounds like sodium nitrate, which are soluble in water, dissolve quickly and therefore may be drained out of the soil instead of being used as food by plants. Commercial fertilizers usually lose most of their value after one season.

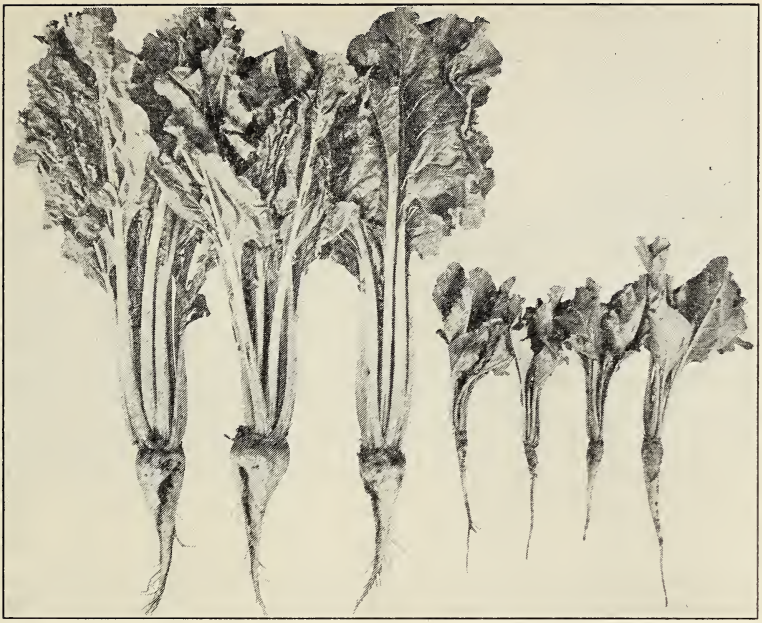
After alfalfa, clover, peas, beans, or other legumes have been grown in a field, the soil contains more nitrogen than it did before. The increase of nitrogen is due to the work of bacteria called *nitro-*

gen fixation bacteria, which grow on the roots of legumes. These bacteria take nitrogen from the air and use it in making nitrogen compounds which can be used by the plant. Since more nitrogen compounds are produced by the bacteria than are used by the plant, the surplus remains in the soil and can later be used by other plants. Research has shown that this method of producing nitrogen compounds is one of the cheapest ways of supplying them to soil. Then, too, clover and alfalfa are excellent crops to prevent soil erosion.

Although the natural supply of nitrogen compounds is very limited, the air is a huge storehouse of free nitrogen which can be made into nitrogen compounds by the use of electric energy. Prior to the World War manufacturing plants which produced nitrogen compounds from the air had been established in several nations. Practically nothing in this industry had been accomplished in the United States, however, until war time needs (nitrogen compounds are necessary in the manufacture of explosives) forced us to realize its importance as a factor in our national security.

Since we could not get nitrogen compounds from other countries, our government in 1917 contracted for the building of a plant to manufacture our own. This plant was located at Muscle Shoals because the water power from the Tennessee River could be used to generate electric energy capable of producing yearly thousands of tons of nitrogen compounds from the free nitrogen in the air. Even though we may never again need the nitrogen compounds from these fixation plants for the manufacture of explosives, they can be used for fertilizers, thus reducing the cost and thereby extending the use of fertilizers containing larger amounts of nitrogen. Thousands of tons of nitrogenous fertilizers are produced annually in nitrogen fixation plants.

Phosphorus compounds as plant foods. Phosphorus is another element required by plants in greater quantity than is found in most agricultural soils. The uses of phosphorus to plants are not definitely known. In a sufficient quantity it stimulates root growth (Fig. 148) and it is present in proteins. Plants remove phosphorus from the soil. Phosphorus may be returned to the



Courtesy U. S. Dept. of Agriculture

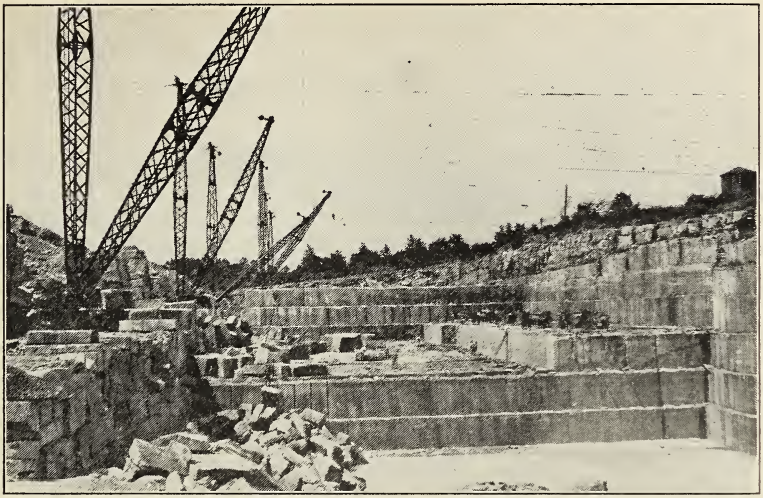
FIG. 148. The sugar beet plants on the left were fertilized with phosphates. Do you think that the use of fertilizers containing phosphates would be particularly helpful in growing sugar beets?

soil by plowing under growing plants or other plant materials, or by the addition of barnyard manure and other organic fertilizers, such as packing house wastes and ground bones (bone meal). These sources of phosphorus compounds are entirely inadequate to fertilize all the farm land which needs phosphorus to promote plant growth. The great part of phosphorus fertilizers come from natural deposits of phosphate rock. Phosphate rocks are mined in Florida and Tennessee. Several million tons are taken from these mines each year. The greatest known deposits of phosphate rock in the United States are situated in a region north of Great Salt Lake, in Wyoming, Montana, and Idaho. This supply is located so far from manufacturing plants and agriculture areas that the cost of shipping makes its use prohibitive at the present time. Phosphate rock is manufactured into phosphate fertilizers at Muscle Shoals. This is the largest production plant of phosphate fertilizers in the United States. The fertilizers produced here contain 45 per cent to 65 per cent of available phosphorus compounds. The waste product known as slag obtained in the manufacture of steel contains much phosphorus; it, too, is used as a fertilizer.

Potassium compounds as plant foods. Potassium is required by plants for underground growth. In some way it is connected with the manufacture of carbohydrates (sugars and starches) by plants, although it is not a part of carbohydrates as a finished product. Furthermore, a lack of this element in the soil makes plant life more susceptible to disease. The ash of many common grains, vegetables, and fruits, and the stems of woody plants contain potassium carbonate, often called potash, indicating the need of this element in plant food. Why? Wood ashes are an excellent source of potassium, but these of course are not available in sufficient quantities. The chief sources of potassium as a fertilizer are certain minerals found in natural deposits in Germany and France. In the United States large potash deposits have been developed in the West, notably in New Mexico. These deposits give the country a source of fertilizer rich in potassium. Natural deposits of certain potash minerals in the Tennessee Valley might supply our potash needs in time of a national emergency.

The use of lime in soils. Compounds of calcium, such as powdered limestone (Fig. 149) and air slaked lime, are added to the soil largely to correct acidity, i.e., a sour condition caused chiefly by the acid wastes given off by the roots of plants. Many soils are improved by the addition of lime because the lime favors growth of certain bacteria in the soil which in turn promote plant growth.

How to find out what plant food is lacking in soil. As a rule commercial fertilizers are mixtures containing compounds of the elements that need to be added to agricultural soil to keep it productive. Compounds of nitrogen, phosphorus, and potassium are especially needed for this purpose. The amount of each needed in a given mixture varies with the crop to be raised and the nature of the soil to be fertilized, e.g., potatoes grow best in

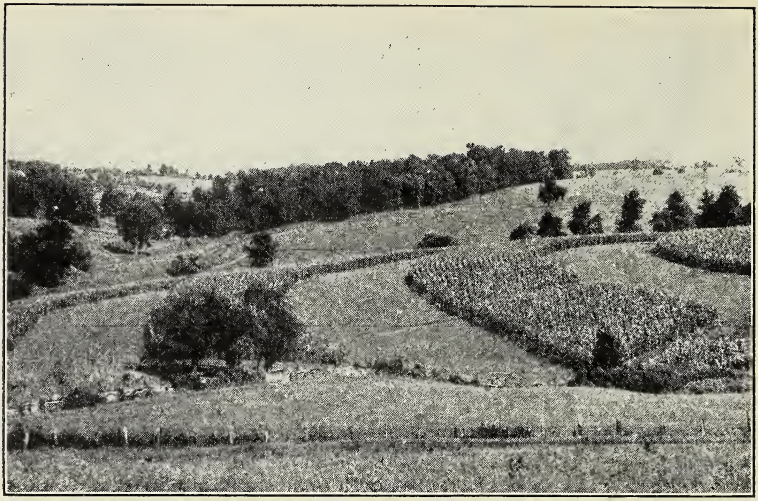


Courtesy Indiana Limestone Corporation

FIG. 149. A limestone quarry near Bedford, Indiana, from which blocks of limestone are being cut. After the stone is cut, derricks lift the blocks out. Limestone is one compound which is of great use to man.

soil containing an abundant supply of potassium, while grain requires a soil rich in phosphate. Therefore, instead of using a fertilizer containing compounds of all three elements, the scientific way is to experiment to discover the kind of fertilizer best suited to grow a particular crop on a particular soil.

To carry out such an experiment, a small plot of ground can be divided into several equal areas, or boxes containing the same kind of soil may be used (Fig. 147). In one box sodium nitrate may be added to the soil; in another, rock phosphate; in another, potassium nitrate; in another, lime; and in still other boxes combinations of different fertilizers. The same kind of seed and the same amount should be planted in each box. A comparison of the yield obtained from the different boxes will give a definite measure of the relative value of the different fertilizing materials. Bulletins issued by agricultural experiment stations in many states or by the United States Department of Agriculture give accurate information concerning the fertility of a soil and the fertilizers needed to make it productive.



Courtesy Soil Conservation Service

Fig. 150. Explain how strip cropping helps to prevent soil erosion.

How to prevent loss of the soil. Since the white man settled this country, about one third of our most valuable possession, the soil, has washed and blown away. A rain of one hour's duration may change a wagon track through a newly plowed field into a small gully. Every year thousands of tons of rich top soil are carried by water from farms into the oceans. The removal of the forests, the burning of the grassy plains, and the extensive cultivation of the prairies have exposed to the weather great regions of open tilled land. In years of extremely low rainfall there has developed a new menace, the "black blizzard" called a dust storm.

Nature requires from 400 to 1000 years to build one inch of soil. The United States Department of Agriculture, farmers and others concerned about the devastating losses of soil by water erosion and by dust storms in certain prairie states have made scientific studies of soil conservation. Methods suggested and tried include such activities as: (1) reforestation, (2) terracing, (3) strip cropping, and (4) a return to the use of the land for grazing.

In a forest rain strikes the ground gently and sinks into a bed of leaves, humus, and soil held in place by a mesh of entwining roots. The water is thus stored or permitted to flow slowly to brooks and springs. Trees also break the force of the wind and tend to check the extensive movement of soil by dust storms.

Terraces are cropland dams across the face of cultivated hillside fields. They are ridges plowed and planted just the same as the other parts of the field. They are built to conform to the contour of the field. When row crops are planted so that the rows are in the same direction as the terraces, soil will retain from 85 to 90 per cent of the rainfall.

Strip cropping utilizes the holding power of grass lands for soil and water. Instead of laying out hillside fields in the form of rectangles, they are marked out by strips conforming to the contour of the slopes. Strips of corn, grain, and vegetables are alternated with strips of grass.

The principal cause of dust storms was the conversion of the prairies from magnificent grazing lands into wheat fields. Efforts are being made now to restore parts of these regions to their former state.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

acre foot
agriculture
artificial
clay
cultivation
drainage
lime
fertilizer
fixation
irrigation
loam
nitrate
phosphate
reforestation
sand
silt
soil water
vegetation

Write the number of each item on your paper and after it the word that completes the statement.

1. The small dark particles seen in soil under the microscope are composed of ________ matter.
2. Microscopic plants necessary in the soil are called ________.
3. Soil with particles less than .005 mm. in diameter is called ________.
4. Removing excess water from a field is done by ________.
5. A substance added to the soil to supply necessary plant food is called a ________.

6. Clover is valuable because it furnishes the soil with more ______.

7. Lime is useful on __________ soil.

8. The cultivation of soil to conserve scant rainfall is called: irrigation; drainage; tilling; plowing; dry farming.

9. Nitrogen is made available as food for plants by: bacteria; rock particles; soil water; sun; weeds.

10. A compound put into the soil to furnish plant food is called: loam; soil particle; fertilizer; bacteria; chlorine.

Which of these statements are true? If any are false, re-state them in correct form.

11. A soil composed of small particles becomes warmer in spring sooner than one composed of larger particles.

12. Weeds have no value to the farmer.

13. Wood ashes are an excellent source of phosphorus for the soil.

14. Broken rock is called humus.

15. Early spring crops grow most rapidly in clay soils.

THOUGHT EXERCISES FOR UNIT VI

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Water rises through the soil, due to capillary action.

Questions or Problems

1. What caused the earth to be slightly flattened at the poles?

2. Is a volcanic mountain the cause or the result of a volcanic eruption?

3. How does volcanic activity sometimes cause an earthquake?

4. Do stones increase or decrease in size? Give reasons for your answer.

5. How is it possible for an artesian well to be situated near the top of a mountain?

6. Water below the surface of the earth may sink and then rise. How can this be?

7. Stalactites that are forming in a cave are hollow. Can you tell why this is true?

8. Agriculturists advise the cultivation of growing corn during a dry period. How does this benefit the crop?

9. Why does soil begin to lose fertility when man begins to use it for growing crops?

PROJECTS AND REPORTS

1. Examine the rocks in your community and report the kinds found. Look for fossils. Do the rocks seem to be bent or twisted? If so, describe. What evidences of weathering did you notice? Are there any volcanic effects?

2. Study several stone buildings and report the kinds of stone used, and the particular building values possessed by each.

3. After a hard rain try to find a small delta. Photograph or draw a sketch of it. Discuss your findings with the class.

4. Examine the soil in your neighborhood. Is it sand, clay, or loam? What is its color? Is there evidence of organic matter? Of living organisms? Would drainage or irrigation be beneficial? Is the soil naturally fertile?

5. Devise an experiment to test the need of soil for different kinds of commercial fertilizers.

6. Bring to class a sample of soil and demonstrate the presence or lack of acids in it by the use of litmus paper.

REFERENCES FOR READING AND STUDY

1. Bradley, J. H., *The Earth and Its History.* Ginn and Company.
2. Burges, Austin E., *Soil Erosion Control.* Turner E. Smith & Co., Atlanta.
3. Cole, G. A. J., *Rocks and their Origins.* G. P. Putnam's Sons.
4. Dahlgren, B. E., *A Forest of the Coal Age.* Field Museum.
5. Gibson, C. R., *About Coal and Oil.* Blackie and Son.
6. Gregory, J. N., *The Making of the Earth.* Henry Holt and Company.
7. Gustafson, Axel F., *Conservation of the Soil.* McGraw-Hill Book Company.
8. Hawksworth, Hallam, *The Strange Adventures of a Pebble.* Charles Scribner's Sons.
9. Lee, Willis T., *Stories in Stone.* D. Van Nostrand Company.
10. Nida, W. L., *Farm Animals and Farm Crops,* Chapters XI and XIII. A. Flanagan Company.
11. Reed, W. M., *The Earth for Sam.* Harcourt, Brace and Company.
12. United States Department of Agriculture, Bulletins and Photographs.
13. *Wonder Book of Nature,* Earth, Sea, and Sky, pages 1-76. Ward Locke and Company.
14. Bulwer-Lytton, *Last Days of Pompeii.* E. P. Dutton and Company.

UNIT VII

WHAT SIMPLE BUILDING MATERIALS MAKE UP THE UNIVERSE?

Exploring the Nature of Matter

One day in a public park a father was seen taking his small son up a steep, rocky path. The father seemed to be in a hurry and his grip on the boy's hand made the short legs of the boy cover more distance than they would have under other circumstances. In the midst of their silent and hurried climb, the boy suddenly asked, "Daddy, what are rocks made of?"

Undoubtedly, this small boy asked the same question that thousands of boys and girls and adults, too, have asked many times. "What is it made of?" is a common question. You know that a table is made of wood; but what is wood made of? You know that your body is made of flesh; but what is flesh made of? Your clothing is made of cotton, silk, linen, wool, and leather. Are these materials made of others or are they single substances?

If this same boy had seen a burning house, in all probability he would have been as curious about it as he was about the rocks. He might have asked, "What makes the fire burn and where does the house go when it burns?" Do you suppose he would have believed a person who told him that the fire had only changed the material of which the house was made, and that the material had not been destroyed? In fact, would you believe a person who told you that all materials can be changed from one form into another but that they cannot be destroyed?

Scientists have discovered much about the materials of which our earth and everything on it are composed. In fact, they tell us that the whole world and everything on it is composed of matter. All changes in this matter are caused by energy. You know the sun is the source of all our energy. You will learn more about energy as you continue your study of science. But what about matter? Would the small boy have been satisfied if the father had told him that rocks are matter?

CHAPTER XV

OF WHAT MATERIALS IS THE UNIVERSE COMPOSED?

Do you know:

That air can be changed into a liquid? What dry ice is made of? That the weight of the earth has not changed appreciably since the earth was formed?

That you and everything else in the world are made of only ninety-two kinds of building "brick"? That every building brick in your body is in constant motion? That the building bricks of which air is made are moving at least thirty times as fast as the fastest train?

What gives fruits a sour or tart taste? How steel is made? That glass is made of sand?

PROBLEM: WHAT IS MATTER? CAN IT BE CREATED OR DESTROYED?

What is matter? In the study of science, matter and energy are very closely related. Every bit of material in the universe is matter. We say that a house is made of wood, stone, plaster, slate, and other materials. Yes, that is true; but from the point of view of science these substances are called matter. The term matter includes the materials of which every solid, liquid, and gaseous substance in the universe is composed. Scientists have defined matter as anything that occupies space and possesses weight. Can you think of anything used in everyday work that does not occupy space and possess weight?

Are matter and energy closely related? In answering the question at the close of the preceding paragraph you may have mentioned light, heat, or electricity. These are not matter; they are forms of energy. *Energy* is defined as the ability to do work.

Whenever matter is moved or changed, some form of energy makes the movement or change possible.

Suppose you are watching an approaching thunderstorm: dark clouds are moving swiftly; flashes of lightning are seen; the wind rises threateningly. The clouds and air are matter; the movements of the air and clouds are made possible by energy; the flashes of lightning are due to electric energy. From this illustration you can see how closely matter and energy are related.

Another example of this close relationship of matter and energy is an automobile racing down the road; the automobile is matter; its movement is due to energy. Your body is matter; yet it is also a manufacturing plant which generates energy from food in order that you may live and move. For young people beginning the study of science the statement cannot be repeated too often that matter and energy make up the universe and that they are present in every act of our daily lives. They are so closely related that any change in matter also involves change in energy. In fact, modern scientists are investigating the possibility of changing one of these into the other; that is, changing matter into energy or energy into matter. We shall learn more about energy in Chapter 16.

What are the three states of matter? Matter exists in three states: (1) as a *solid* (the chair in which you sit); (2) as a *liquid* (the water you drink); and (3) as a *gas* (the oxygen in the air you breathe).

Experiment 62. To show in what states of matter water exists. Place a piece of ice in an evaporating dish and heat gently until all the ice is melted. Continue to heat the dish until the water has been completely evaporated. What are the three states of matter in which water existed in this experiment?

Can all kinds of matter be changed from one state into the other two? In Experiment 62, when the ice (a solid) was heated, it became water (a liquid); when the water was heated, it became steam (a gas). Many other solids, such as iron, can be changed into two other states of matter; i.e., to liquids and gases.

A gas like oxygen can be changed first into a liquid and then into a solid, by subjecting it to great pressure or by cooling it to a very low temperature. Usually, however, both pressure and a low temperature are used at the same time. Why do you think this is done? As you have already learned, one very common gas, carbon dioxide, has several commercial uses in its solid state. For instance, it is used under the trade name "dry ice" to keep ice cream from melting.

Of all the known gases helium is the most difficult to liquefy. However, it has been liquefied at a temperature of 452° below zero F., and made into a solid at 458° below zero F.

Do you believe that such liquids as mercury, gasoline, and alcohol can be changed into the two other states of matter?

Of course not all substances can be changed from one state of matter into another. Sugar, for example, cannot be changed by heat into liquid sugar. Can you make liquid wood or cloth? Solid iodine when heated changes directly into a gas; if iodine gas is cooled, it changes directly into solid iodine. Although not every substance exists in all three states of matter, all matter in the universe exists in at least one of these states: a liquid, a gas, or a solid.

Matter undergoes many changes. Everything about us is undergoing change. In spring the snow and ice melt. Grass and flowers grow and cover yards, parks, and fields with a green carpet. In fall and winter these plants change, becoming brown and appearing lifeless. Our clothes wear out and have to be replaced. Dishes are broken and thrown away. Wood and coal are burned and disappear. These statements are sufficient to remind us that everything about us is undergoing change. Name other changes.

Experiment 63. To show that salt undergoes a change when dissolved in water. Dissolve about one gram of salt in about 20 cc. of water. Taste the solution. What has happened to the salt? Has the salt changed? Now heat the solution until all the water has evaporated. Taste the residue. What is it?

Although the salt underwent a change in this experiment, it did not change into anything else. When a substance undergoes a change but does not change into another substance we say it has not changed in *composition*.

What is a physical change? A glass tumbler is broken; the glass is changed in form but not in composition. A baseball bat is broken, but the pieces are still wood; the wood is changed in form but not in composition. When apples and potatoes are peeled they are changed in form and appearance but no new substances are produced nor has anything been destroyed.

When you performed Experiment 62 you learned that heat changed ice into water and water into steam. During these two changes the composition remained the same. Changes like these are taking place at all times. Water is being evaporated and the water vapor is being carried up into the sky. Where does the energy come from which causes this change? High above the earth the air is cooler and here the water vapor condenses. Water vapor, a gas, has been changed to water, a liquid; still the composition remains the same. If the temperature of the upper air is low enough, the liquid, water, is changed to a solid, snow or ice; still the composition is unchanged.

If you are familiar with the use of solder you know that it is melted and applied to two pieces of metal which are to be joined and allowed to cool. Although the solder was changed to a liquid and then back to a solid, the composition of the solder did not change. The melting and the solidifying of any metal are changes of this kind. Any change which a substance undergoes, provided the composition remains the same, is known as a *physical change.* These changes are accompanied by energy changes. Mention other examples of physical changes.

Experiment 64. To show that a change takes place when milk sours. Seal the cap on a pint bottle of sweet milk, airtight, with paraffin. Weigh the bottle of milk and record the weight. Keep the bottle, sealed tightly, in the open air in the room and reweigh every day for five days. Has the bottle of milk changed in weight during the five days? Unseal the bottle. Does the milk have the odor, taste, and appearance of sweet milk? What has happened to the milk? Has the milk undergone a change?

What is a chemical change? In the preceding experiment we say that the milk has soured. The odor and taste of the sour milk would indicate that its composition is different from that of sweet milk. The souring of milk is a chemical change. When iron rusts, the iron unites with oxygen, producing another form of matter called iron oxide. The rusting of iron is a chemical change. Any change in the composition of matter is known as a *chemical change.* Chemical changes are accompanied by energy changes. In every chemical change energy is either taken in or given off. Mention other examples of changes that you have observed and which you think are chemical changes.

Can matter be either created or destroyed? If the salt in Experiment 63 had been weighed before it was dissolved in water and weighed again after the water was evaporated, we would have found that the weight was the same. Was the weight of the milk after it had soured the same as when it was sweet? As the bottle was sealed tightly, nothing could enter the bottle. Many experiments such as these have led scientists to make the statement that, during all the changes through which any given weight of matter may pass, the total weight remains the same. In other words, matter can be changed in form but it can neither be created nor destroyed.

Let us consider whether the earth, including its atmosphere, has gained or lost in weight since its formation, as a result of the countless number of physical and chemical changes that have taken place upon it. Rivers have carried whole mountains to the sea. Immense forests have been burned and the gases thus formed have passed into the atmosphere. Glaciers have changed hilly country to level plains. Great numbers of cities have been built and destroyed. Millions of tons of coal have been burned. Billions of gallons of gasoline have been changed into gases. If scientists are correct, these changes have made no measurable difference in the total weight of the earth, including its atmosphere. In a few ways, perhaps, the weight of the earth has been slightly changed; meteors have added a little weight, and very light gases may have escaped from the atmosphere. In general, however, we may say that, notwithstanding all the chemical and physical changes that have taken place during the long and remarkable history of our planet, the earth's total weight has remained the same; matter has neither been created nor destroyed.

PROBLEM: WHAT IS AN ELEMENT, A COMPOUND, A MIXTURE?

What is an element? In our discussion of matter, we have not said anything about its composition. Let us now see what matter is made of. Scientists have discovered in nature ninety-two different substances each of which is called an *element.* These elements and combinations of them form the matter in the universe. Just as there are only twenty-six letters from which all the words in the English language are made, so there are only ninety-two elements from which all the different substances in the universe are made. These elements form all of the rock portion of the earth including the soil, all the plant and animal life, all the water, and the atmosphere (Fig. 151).

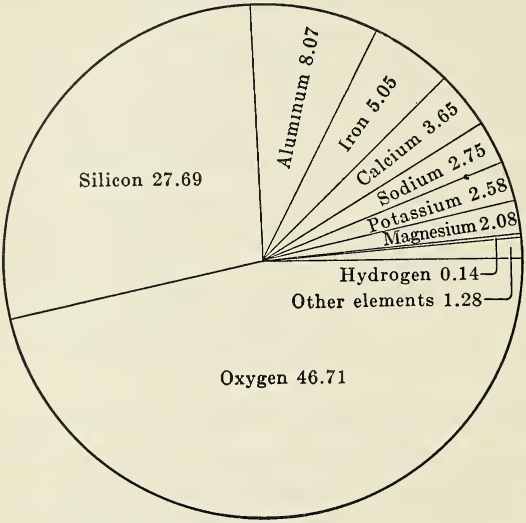


FIG. 151. This graph shows in per cents the weights of the elements in the earth and the living things on it. Which element makes up the greatest per cent?

Of what is an element composed? An element is built up of very small "building bricks"; one of these building bricks is called an *atom.* All the atoms of the same element are alike; atoms of different elements are unlike. Atoms are too small to be seen with the most powerful microscope; yet, in spite of their minute size, scientists know a surprising amount about them; they even know the weight of the atoms of most elements. Theories have been proposed as to their composition and structure.

In recent years scientists have made wonderful discoveries about the atom. At one time an atom of hydrogen was thought to be the smallest particle into which hydrogen could be divided. Scientists now advance the theory that an atom of hydrogen is made up of a particle of positive electricity called a *proton,* around which is moving a particle of negative electricity called an *electron.* An atom of helium is made up of four protons and four electrons. An atom of oxygen is made up of sixteen protons and sixteen electrons. According to this theory it follows that an atom of any element is made up of a nucleus of protons and electrons with some free electrons moving about the nucleus.

You see from the foregoing paragraph that an atom of hydrogen differs from an atom of oxygen, owing to the different amounts of electricity which make up the two atoms. You should keep in mind that an atom is made up of protons and electrons and that an atom of one element differs from an atom of another element in the number of its protons and electrons and in their arrangement.

How is the structure of the atoms of the elements used to classify them? In 1914 H. G. Mosely, a young British scientist, arranged the elements in a "chemical ladder" with the positions on this ladder numbered from 1 to 92. The first position on the ladder is occupied by the element hydrogen, because it has only one proton; helium occupies the second position on the ladder because an atom of helium has fewer protons than any other element except hydrogen. At the very end of the ladder in position ninety-two is uranium; its atom has more protons than any other.

Most of the elements have been known for many years. The last six have been discovered since 1923. Number 72, called *halfnium,* was identified in 1923 by Professor D. Coster and Dr. George von Hevesy. Numbers 43 and 75 were discovered in 1925 and 1926 by Dr. Walter Noddack and his collaborators and named *masurium* and *rhenium* respectively. Number 61, the first element to be discovered by an American, was found in 1926 by B. S. Hopkins of the University of Illinois; it was named *illinium* in honor of that institution. Dr. Fred Allison of the Alabama Polytechnic Institute discovered elements 85 and 87 in 1931; they were named *alabamine* and *virginium* respectively.

His work has been verified by Professor J. L. McGhee and Margaret Lawrenz of Emory University. In the light of our present knowledge the last element has been found. A list of the commoner elements is given below:

Name	*Symbol*	*Position*	*State*
Aluminum . .	Al	13	Solid
Antimony . .	Sb	51	"
Arsenic . . .	As	33	"
Barium . . .	Ba	56	"
Bismuth . .	Bi	83	"
Boron	B	5	"
Bromine . . .	Br	35	Liquid
Cadmium . .	Cd	48	Solid
Calcium . . .	Ca	20	"
Carbon . . .	C	6	"
Chlorine . . .	Cl	17	Gas
Chromium . .	Cr	24	Solid
Cobalt . . .	Co	27	"
Copper . . .	Cu	29	"
Fluorine . . .	F	9	Gas
Gold	Au	79	Solid
Hydrogen . .	H	1	Gas
Iodine . . .	I	53	Solid
Iron	Fe	26	"
Lead	Pb	82	"
Magnesium . .	Mg	12	"
Manganese . .	Mn	25	"
Mercury . .	Hg	80	Liquid
Nickel . . .	Ni	28	Solid
Nitrogen . . .	N	7	Gas
Oxygen . . .	O	8	"
Phosphorus . .	P	15	Solid
Platinum . .	Pt	78	"
Potassium . .	K	19	"
Silicon . . .	Si	14	"
Silver	Ag	47	"
Sodium . . .	Na	11	"
Sulfur	S	16	"
Tin	Sn	50	"
Zinc	Zn	30	"

How do we write the names of elements? To avoid writing the names of the elements, chemists have agreed on an abbreviation for each, called its chemical symbol. Read the table above. It contains the symbol for an element, its position on the chemical ladder and the physical state in which it usually exists.

What is a compound? Elements unite to form *compounds.* Although there are only ninety-two elements, the number of compounds formed from these is countless; for example, there are more than 200,000 compounds containing the element carbon. After analyzing thousands of samples of pure water scientists tell us that 18 grams of water are always composed of 16 grams of oxygen and 2 grams of hydrogen. In other words a definite weight of oxygen unites chemically with a definite weight of hydrogen to form a definite weight of water. The weight of the water is equal to the weight of the oxygen plus the weight of the hydrogen. Similarly, 44 grams of carbon dioxide are always composed of 12 grams of carbon and 32 grams of oxygen. From these and many other analyses, scientists have concluded that the composition of a given compound never varies; i.e., it is always made up of definite weights of the same elements.

What is a molecule? The smallest particle into which a compound can be divided is a molecule. For example, the smallest particle of water that can exist is a molecule of water. If a molecule of water is broken up, it is changed into two atoms of hydrogen and one atom of oxygen. If a molecule of carbon dioxide is broken up it is changed into one atom of carbon and two atoms of oxygen.

Although a molecule is made up of two or more atoms, it is itself very small. A molecule, like an atom, is so small that it is not visible with even the most powerful microscope. In speaking of the size and number of molecules, Dr. Irving Langmuir has said that if the molecules in one cubic inch of air were each increased to the size of a small grain of sea sand, they would fill a trench a mile wide and three feet deep reaching from New York to San Francisco. We cannot imagine a particle as small as a molecule, nor can we imagine a quantity as great as the number of molecules in a cubic inch of air. Another famous scientist, Sir James Jeans, has estimated the number of molecules in a cubic inch of air to be represented by a number consisting of 10 followed by forty-one zeros. Write this number.

What is molecular activity? Molecules are thought by scientists to be in rapid motion. Their activity depends upon the temperature of the substance; that is, as a substance is heated, its *molecular activity* increases. A metal gives an indication of this increase in molecular activity when heated by expanding slightly in all directions. When a metal is heated sufficiently to become a liquid, the activity of the molecules is so greatly increased that the molecules separate enough to pass over and around each other freely. If the liquid metal is heated until it becomes a gas, the activity of the molecules is so greatly increased that it causes them to move rapidly away from one another unless they are in a closed container. When a gas is heated, the increased speed of its molecules causes them to move farther and farther apart, consequently the gas expands if it is free to do so.

On the other hand, if heat is withdrawn from a metal in a gaseous state, its molecular activity is decreased. If enough heat is withdrawn, the molecular activity decreases until the gas becomes a liquid. If enough more heat is withdrawn, the molecular activity is still further decreased, and the liquid metal will become a solid again. What energy changes took place as the solid metal changed into a gas? As the gas changed back into a solid metal?

How fast do molecules move? If the air in a room is at a temperature of 70° F., the average speed of the molecules is about 540 yards per second. As a fast train moves at a rate of about 23 yards per second, you can see how very, very fast molecules move. When air is at a temperature of 32° F. the molecules move a little less than 530 yards per second. How much slower is the movement than at 70° F? Would you think it necessary to have a very low temperature in order to slow up the speed of air molecules sufficiently to produce liquid air?

What is a mixture? Did you ever have the misfortune to spill a bag of sugar on the ground? If so, you know how well the sugar mixed with the dirt. In science such an intermingling of matter is called a *mixture.* Perhaps in cooking you have mixed flour and salt. The result of this intermingling of flour and salt is a mixture. From your study of the atmosphere you know that it is a mixture because it is made up of nitrogen, oxygen, and other gases intermingled. Such substances as mortar and soil are also mixtures. Why? Mixtures represent an even larger group than compounds, because an intermingling of any two or more compounds would make a mixture. Owing to the great variety of mixtures, each of which is different from the other, it is necessary to study each individual mixture by itself if we wish to determine its composition.

What is an alloy? A mixture of two or more metals melted together is called an *alloy*. As you study this chapter you will learn about many of the important alloys.

PROBLEM: WHAT ARE SOME OF THE COMPOUNDS USED IN EVERYDAY LIFE?

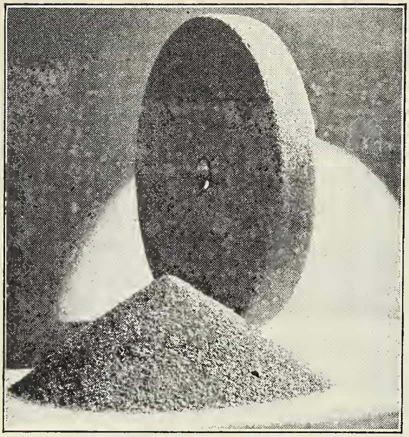
What is an oxide? As oxygen unites readily with almost every one of the other elements to form compounds, it is said to be a very active element. When an element unites with oxygen, a compound of that element and oxygen is formed. Such a compound is called an *oxide*. For example, when a candle, composed chiefly of carbon and hydrogen, burns, the carbon in the candle unites with oxygen from the air to form carbon dioxide; the hydrogen in the candle unites with oxygen from the air to form water, which is an oxide of hydrogen. Many other elements, such as iron and sulfur, unite with oxygen to form oxides.

The abundance of oxygen, as compared with that of the other elements that make up the earth's crust, is shown by the following table:

Name of element	*Per cent of weight of earth's crust*	*Name of element*	*Per cent of weight of earth's crust*
Oxygen	46.71	Potassium	2.58
Silicon	27.69	Magnesium	2.08
Aluminum	8.07	Titanium	.63
Iron	5.05	Hydrogen	.14
Calcium	3.65	Phosphorus	.13
Sodium	2.75	Carbon	.03

The twelve elements listed in this table compose what per cent of the earth's crust? All the other elements, including gold, silver, sulfur, and mercury, compose the remaining one per cent.

Are oxides useful to man? Many oxides, in addition to water and the others just mentioned, are used for practical purposes. Aluminum oxide is found in the earth in many forms, one of which is a crystalline substance. The crystals are very hard and are used in manufacturing polishing and grinding wheels. Aluminum oxide also occurs in noncrystalline form. Certain kinds of it are melted, fused in an electric furnace; thereby crystalline aluminum oxide is produced. Calcium oxide (lime) is used in making whitewash, mortar, and plaster; in preparing ammonia and bleaching powder; and in removing hair from hides in the process of tanning. Lead oxides are used in the preparation of certain paints, varnishes, glazes for pottery, and flint glass. Nitrous oxide, laughing gas, is frequently used as an anaesthetic in minor surgical operations. Zinc oxide is used extensively in making paints and rubber goods.



Courtesy Norton Company

FIG. 152. A polishing wheel and a pile of fused crystalline aluminum oxide. The wheel is made of felt to which aluminum oxide is held by glue.

What is an acid? Some compounds in a water solution, such as vinegar, have a sour or tart taste. This sour taste, as well as that of most fruits, is due to the presence of a compound known as an acid. In Experiment 33, the preparation of hydrogen, we poured hydrochloric acid over zinc. The hydrogen in the acid was replaced by zinc, while hydrogen escaped as a gas.

Experiment 65. To show how to identify an acid. Dip a separate piece of blue litmus paper into each of three or four weak solutions of different kinds of acids. What happens to the litmus paper in each case? The turning of blue litmus paper red is a common test for the presence of an acid.

An *acid* is a compound of hydrogen that (1) has a sour taste in a solution of water, (2) turns blue litmus paper red, and (3) gives up its hydrogen atoms when uniting with a metal.

Are acids useful to man? Acids much used in the laboratory are hydrochloric, sulfuric, and nitric. Sulfuric acid is valuable because of its wide use in making other acids. Hydrochloric acid is used in the preparation of chlorine for bleaching powder, also in cleaning metals and in the manufacture of glue and gelatin. A small amount is found in the gastric juice of the stomach, indicating that it is necessary in the process of digestion. Nitric acid dissolves silver but not gold, and therefore is sometimes used to separate those two metals when they form a mixture. It is used in the manufacture of nitroglycerin and guncotton. Nitric acid is also used extensively in the manufacture of many kinds of dyes and drugs.

What is an organic acid? Acids, called organic acids, are composed of carbon, hydrogen, and oxygen. The most common of these organic acids is acetic acid produced by fermentation and the action of bacteria on fruit juices, especially apple cider. It is the acid in vinegar. Other organic acids are malic acid found in apples, pears, cherries, currants, and gooseberries; tartaric acid found in grapes; citric acid found in oranges, lemons, and grapefruit; lactic acid, produced when milk sours; and butyric acid, one of the acids that give rancid butter its disagreeable taste and odor.

Is vinegar an acid? Vinegar is a solution of water and acetic acid. From 4 to 8 per cent of the solution is acetic acid. The sugar in cider from which vinegar is commonly made is changed slowly into alcohol by the action of yeast plants which fall into it from the air. Such cider is called "hard cider." The alcohol in the hard cider is in turn changed into acetic acid by acetic acid bacteria. Large numbers of these bacteria make up the characteristic slimy substance known as "mother of vinegar." The sour taste of vinegar is caused by the acetic acid present.

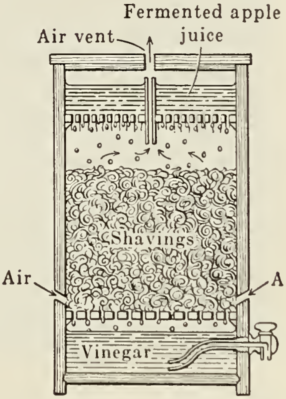
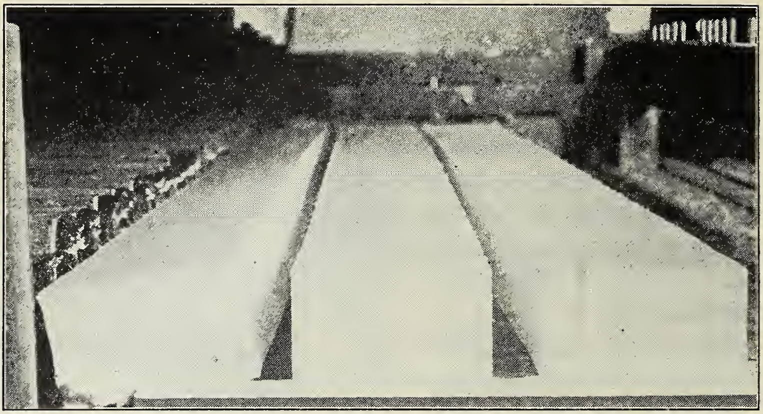


FIG. 153. A large, barrel-like cask in which the process of changing cider into vinegar is under way. What do you think is the purpose of the air vents?



Courtesy Procter and Gamble Company

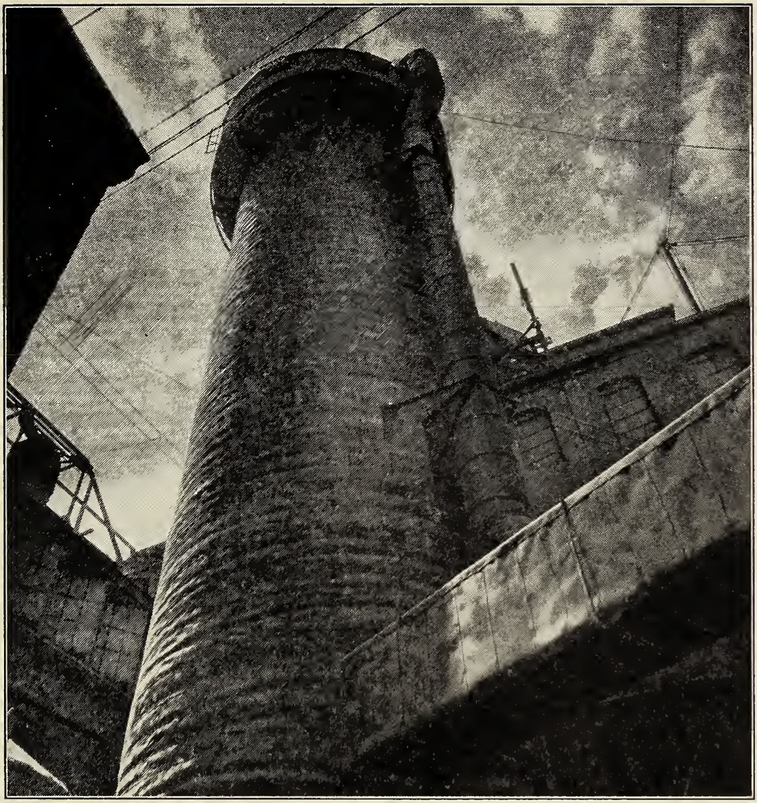
Fig. 154. Soap is a compound made from oils, fats, and caustic soda. These huge slabs of soap were sliced by piano wires. Smaller slabs and even bars are sliced in the same way.

This process of changing sweet cider into vinegar used to require several weeks, but by modern methods the changes are brought about in a few hours (Fig. 153). If pure alcohol is used instead of cider, the vinegar is colorless and is sometimes referred to as distilled vinegar.

What is a base? Another large class of compounds has properties which in a number of respects are the opposites of the properties of acids. These compounds are called bases.

Experiment 66. To show how to identify a base. Test a weak solution of sodium hydroxide, one of potassium hydroxide, and one of calcium hydroxide with red litmus paper. What happens to the litmus paper in each case? The turning of red litmus paper blue is a common test for the presence of a base. Rub a small amount of each of the solutions between your fingers. Describe the feeling.

A *base* is a compound which consists usually of a metal, such as sodium, potassium, or calcium, combined with oxygen and hydrogen. It has (1) a soapy feeling, (2) a bitter taste, and (3) turns red litmus paper blue. The three bases used in Experiment 66 are sometimes called *alkaline solutions* or *alkalies*.



Courtesy Procter and Gamble Company

Fig. 155. At the top of this high tower semi-liquid soap sprayed through small openings in nozzles falls through the air to the bottom. Why do the particles of soap assume a spherical shape (page 193)?

Are bases useful to man? These three alkaline solutions are quite commonly used in our homes and in the manufacture of other substances that we use. Sodium hydroxide, frequently called caustic soda, decomposes most animal and vegetable matter and is therefore widely used in making soap (Figs. 154 and 155). The fats and oils used in making soap are practically eaten up (decomposed) by a strong solution of caustic soda. This strong alkali is also used in manufacturing paper and dyestuffs and in refining petroleum. Sodium hydroxide is sold for household use under the name of lye. Cuticle removers are weak solutions of sodium hydroxide.

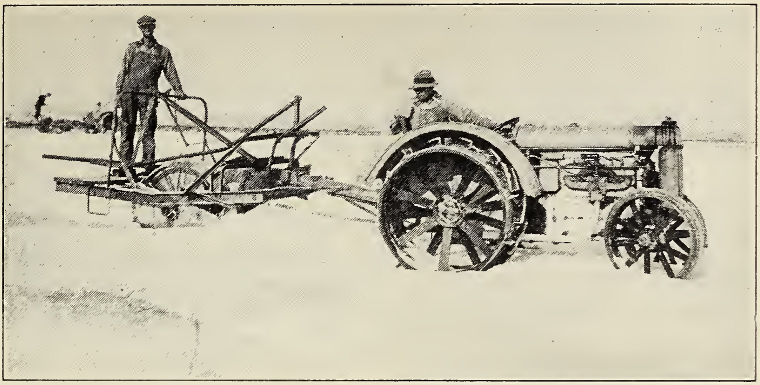
Ammonium hydroxide is used in the home as household ammonia. What use is made of this compound in the purification of water? Potassium hydroxide solution decomposes animal and vegetable matter and corrodes many mineral substances, such as glass and porcelain. Large quantities of it are also used in making soap. A solution of calcium hydroxide and water is known as milk of lime; whitewash is thick milk of lime.

Experiment 67. To show the formation of a salt. Dissolve a small piece of sodium hydroxide (a base) in an evaporating dish or test tube one-third full of water. Add a little dilute hydrochloric acid and stir with a glass rod. Continue to add the acid until the solution turns blue litmus paper slightly red. Now heat the solution over a Bunsen burner until all the water has been evaporated. Does anything remain in the dish or test tube? Taste it. This substance is common table salt. The action of an acid on a base produces a compound to which the general name *salt* has been given. Table salt is just one of many kinds of salts.

Neutralization is the general name given to the uniting of an acid and a base by which water and a salt are formed.

Why do we need salt? Table salt, whose chemical name is sodium chloride, is a compound of sodium and chlorine. It is thought that salt provides the chlorine necessary for the formation of hydrochloric acid, an essential part of gastric juice. Since salt is so necessary to physical well-being, animals as well as human beings often go to much trouble to secure it. Centuries ago one method used to torture prisoners was to furnish them with unsalted food and with rain water, which is free from salt or any other dissolved mineral matter. As a result, they soon died. If used in sufficient quantities, salt will kill weeds and other plants. It prevents the growth of bacteria that cause decay, and for this reason meats are frequently preserved by the use of salt.

Where is salt found? Salt is found in large quantities in nature. Salt is thought to have been deposited in the earth's crust millions of years ago by the evaporation of water from large bodies of salt water. Even today, salt is obtained in some places by the



Courtesy Pacific & Atlantic Photos, Inc.

Fig. 156. Water from Great Salt Lake, Utah, when pumped into shallow ponds evaporates and leaves a layer of salt. This salt is scraped into piles and shipped to a refining plant. Can you suggest a reason why the workers wear dark glasses?

evaporation of water from solutions of salt (Fig. 156). Salt is also secured by boring wells into the salt deposits of the earth. Water is then pumped into these wells. The water dissolves a portion of the salt, forming salt water or brine. The brine is then pumped to the surface and the water evaporated, either by heating or simply by exposing the solution to the air. The salt in some deposits is so pure that when it is mined and crushed, it is ready for use.

In the United States the largest salt deposits are in New York, Ohio, Michigan, Kansas, and Texas. Even so the amount of salt in these deposits is small when compared to the amount in solution in the sea. While the percentage of common salt in sea water is small, the volume of sea water is so great that the total amount of salt in the sea has been estimated at 36,000,000,000,000,000 tons.

Are salts useful to man? Salts of many kinds are taken from the earth's crust; many kinds are manufactured as well. Many substances used in everyday life are salts. The moving picture industry uses large quantities of two salts—silver nitrate and silver bromide. One of our common household medicines is magnesium sulfate (epsom salts). Mercuric chloride and potassium iodide are other salts used in making medicines. Commercial fertilizers (page 239) are mixtures of salts containing elements that are plant food. Some of the salts used as fertilizers are calcium carbonate, ammonium sulfate, sodium and potassium nitrate. The chief salt used in tooth paste and tooth powder is calcium carbonate. Baking soda is composed chiefly of sodium bicarbonate. Washing soda is composed of crystals of sodium carbonate. Some baking powders are mixtures of potassium bitartrate and sodium bicarbonate. These salts are but a few of the many used in our daily lives.

PROBLEM: WHAT ARE SOME OF THE METALLIC ELEMENTS THAT ARE USEFUL TO MAN?

What is a metal? Some elements have certain characteristics in common. For example, iron, copper, tin, and gold can be melted, and we say therefore that each has the characteristic *fusibility*. They conduct heat and electricity, and therefore each has the characteristic *conductivity*. They can be hammered into thin sheets, and therefore each has the characteristic *malleability*. The fresh surface of each of these elements has the characteristic called *luster*. An element which has these four characteristics, fusibility, conductivity, malleability, and luster is called a *metal*.

What is an ore? Copper, mercury, and gold have been found in small quantities in the earth's crust in a free state, that is, uncombined with other elements. However, they are also found combined with other elements. Because they were present in a free state, these metals were among the first to be used by ancient man. Since the beginning of history pure gold has been used for ornaments and ceremonial vessels. Savages used copper for tools and weapons. Men of the Middle Ages thought that mercury was a magic substance capable of changing all other metals into gold.

All of our other common metals, such as aluminum, iron, tin and lead, are found combined with other elements and are taken from the earth as *ores*. Tin and aluminum are found combined with oxygen, that is, in oxides. Lead, silver, and mercury are found combined with sulfur in ores, that is, in sulfides. Zinc ores are sulfides, oxides, and carbonates. The carbonates of zinc are compounds of zinc, carbon, and oxygen. In order that these metals may be made useful for man, they must be extracted from their ores. The separation of metals from their ores is called *metallurgy*.

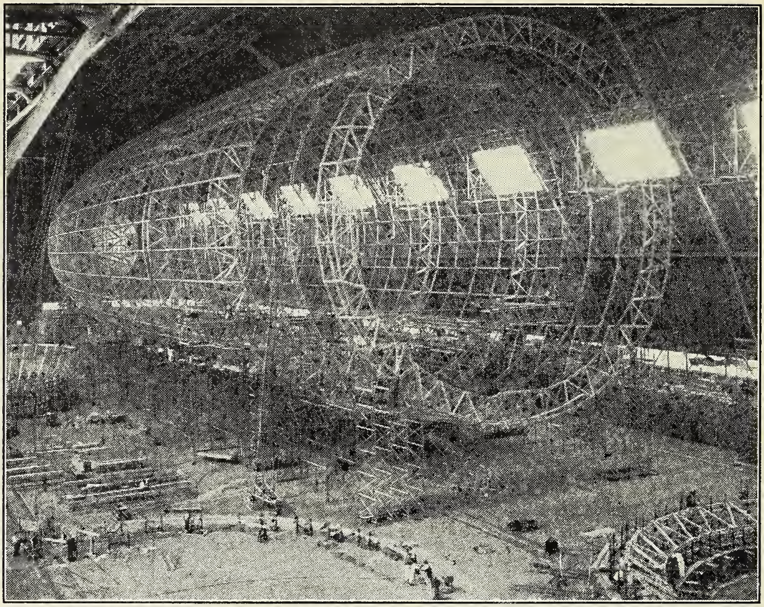
Copper. Copper is one of the most useful of our common metals. Daily, almost hourly, we are making use of copper in one way or another. The lighting of our homes, our transportation, our communication by telephone, telegraph, and radio depend upon the use of copper wires. Household utensils, such as boilers and pans, are made from sheet copper; it is used also for roofing and spouting and screening. Books are printed from plates made by depositing a layer of copper (page 471) on wax forms by means of an electric current. Copper is an element used in making many useful alloys such as gold and silver coins, brass, and German silver. It is also alloyed with tin and other elements to make bronze.

Tin. Tin is found chiefly in the Malay Peninsula, in the Dutch East Indies, and in Bolivia. Pure tin is used chiefly as a coating for iron pans, cups, cans, and other articles. It resists the action of oxygen in air and the many weak acids found in fruits and vegetables, thus preventing iron coated with it from rusting. Tin is alloyed with lead to make tin foil and solder.

Lead. Lead is used chiefly to make alloys for type metal, bullets, and Babbitt metal used for bearings in machines. Lead is also used extensively in making plates for storage batteries (page 472) and in the manufacture of paints.

Zinc. The chief use of zinc is to *galvanize* (coat) iron, thereby preventing it from rusting. Galvanized iron is used in making wire fencing and netting, roofing, water tanks, and furnaces. Zinc is also used for electrodes in electric batteries and in such alloys as brass, bronze, and German silver. Compounds of zinc are also used as a substitute for lead in paints.

Aluminum. The number of uses of aluminum is increasing rapidly as we learn new ones to which it may be put. Aluminum foil is to some extent replacing tin foil. Aluminum is now em-



Courtesy Goodyear Zeppelin Corporation

Fig. 157. The framework of the giant airship Macon was made of duraluminum, an alloy of aluminum. The illustration shows how the circular frames are held together by girders, riveted with duraluminum rivets.

ployed in the manufacture of ornamental articles, cooking utensils, caps for fruit jars, automobile parts, airships, patterns for foundry work, and apparatus needed in scientific work. Aluminum alloys are competing with brass and steel, especially in the manufacture of automobile parts. These alloys have only one-third the weight of steel, and yet are as strong. The building of airships (Fig. 157) depends chiefly upon their use. Railroad trains built of aluminum alloys have proved successful.

Mercury. Mercury, known for ages as quicksilver, is the only metal that is liquid at ordinary temperatures. It solidifies at 38.87° F. below zero and boils at 670° F. It is recognized by its silver color and its liquid form. It is used principally in scientific work and also in barometers and thermometers. Because it dissolves gold and silver, it is used in the metallurgy of these metals.

Gold and silver. On account of their high luster, gold and silver are especially suitable for ornamental purposes. Gold or silver is mixed with other metals to make coins. United States standard gold and silver coins contain 90 per cent gold or silver.

The metallurgy of iron. Iron is the most useful of all metals. Pure iron is so rare that it has been called a scientific curiosity. The alloys of iron, called steel, are so frequently employed in commerce and industry that the present period of civilization is often called the Iron Age. Modern transportation, communication, and architecture have been made possible by this metal. New uses for iron are discovered almost daily.

Ores of iron are found in almost every country in the world. In our country the regions in which most of the iron ore is mined are near Duluth, Minnesota, and Birmingham, Alabama. Are ores of iron found in your locality? The chief ore of iron is an oxide called hematite; it is red in color and furnishes about seventy per cent of the iron used in industry.

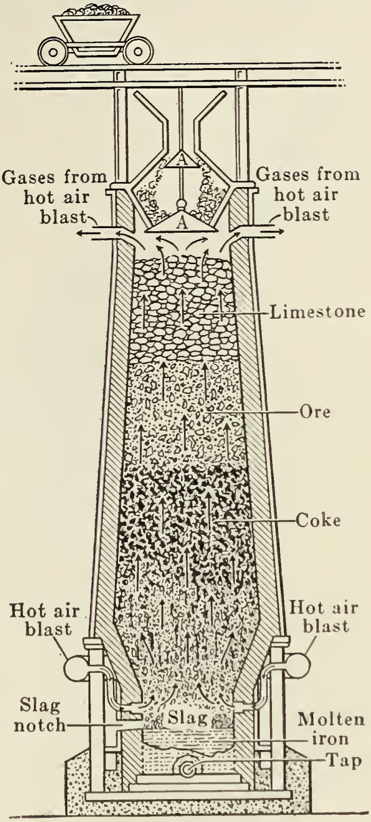


Fig. 158. A blast furnace. How does a blast of heated air assist in the process of making cast iron?

Since iron ore occurs as an oxide, the iron must be freed from oxygen, separated from other impurities, and finally mixed with those elements which are necessary to make a particular alloy steel. Iron is extracted from its ore (*smelted*) in a *blast furnace*, in which the ore is placed with limestone and coke. When coke burns, it unites with the oxygen in the ore, thus freeing the iron; and the limestone unites with the earthy impurities to form a liquid which can be drawn from the furnace. To aid in the smelting process a blast of hot air is forced into the furnace near the bottom.

A blast furnace is so constructed that the smelting process is continuous and thus the furnace may be kept in steady operation. As the iron is freed from the oxygen, it is drawn from the furnace as molten iron (*cast iron*). The impurities (*slag*) are drawn off every few hours. To keep the furnace filled, ore, coke, and limestone are dumped into a trap, A (Fig. 158), at the top of the furnace. This trap prevents the escape of the hot air blast while this work is going on.

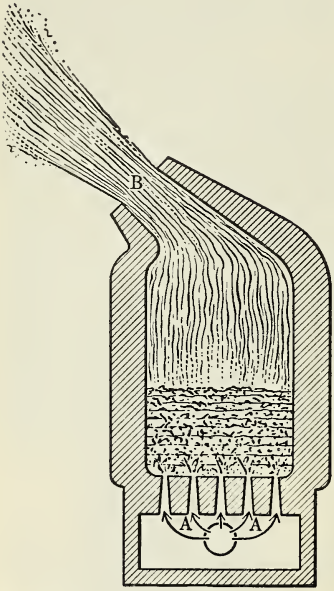


FIG. 159. Vertical section of a Bessemer converter in operation. *A* indicates the openings through which a hot blast of air enters the converter. At *B* heated gases are leaving the converter.

How is steel made? Cast iron has relatively few uses because the impurities in it make it so brittle that it is easily broken. In order to make a material more suitable for industrial purposes than cast iron, it is made into steel in either a *Bessemer converter* or an *open-hearth furnace.*

Bessemer steel is produced in an egg-shaped furnace called a *converter*, made of wrought iron and lined with heat-resisting material, usually fire brick. The bottom of the converter is perforated with holes to admit a blast of air (Fig. 159) which forces its way through the molten cast iron. Oxygen from the air unites with the carbon, silicon, and any other impurities to form carbon dioxide, silicon dioxide, etc. The blast continues from fifteen to twenty minutes, or until the color of the flame from the converter shows that the impurities have been burned out of the iron. Different kinds of steel require different amounts of carbon. To secure the desired amount of carbon in a particular kind of steel, a certain quantity of iron in which the percentage of carbon is definitely known (spiegel iron) is thrown into the converter.

The open-hearth furnace consists of a large rectangular hollow bed lined with fire brick and covered with sand on which molten cast iron is poured. By passing hot gas and hot air over the molten cast iron, the phosphorus, sulfur, and other impurities by uniting with oxygen are removed, and the carbon is reduced to the amount desired in the steel. The open-hearth process requires a longer time to make steel than the Bessemer converter process, but it has a number of advantages, one of which is that from time to time a sample of the metal taken from the furnace may be tested. When the tests show that the steel is the quality desired it is drawn off from the bottom of the furnace. Because the slag is lighter and floats on the steel it is drawn off after the steel has been taken from the furnace.

Kinds of steel. Certain elements either unite or mix with iron to form steel. Some of these elements are carbon, silicon, cobalt, chromium, nickel, molybdenum, manganese, tungsten, and vanadium. Probably all kinds of steel contain minute quantities of carbon. Steel which contains about 36 per cent of nickel has practically no expansion when heated. Silicon steel is used in making cores for electric transformers and generators. A steel having great tensile strength contains vanadium, chromium, and nickel. High speed or self-hardening steel used for machine tools contains tungsten, molybdenum, chromium and vanadium. Machine tools made of this steel do not lose their cutting edge when heated to a dull red. Chromium steel has a multitude of uses. It is a shiny, silvery white metal that does not corrode or rust. This steel is used to make tables, chairs, lamps, kitchen sinks, milk cans, and flatware. On account of its durability and resistance to corrosion and rust, it is used as facings on buildings. The silvery white exterior of many modern buildings is due to the use of this steel. It has helped to usher in a new type of architecture.

Calcium and some of its useful compounds. Although the metal calcium itself has almost no commercial value, its com-

Courtesy Indiana Limestone Corporation

FIG. 160. Limestone from the quarry shown in Fig. 149 was used in the construction of this building, the Cook County Criminal Courthouse, Chicago. As limestone is both beautiful and durable, it is one of our chief building materials.

pounds are among the materials most useful in our modern civilization. The most common compound of calcium found in nature is calcium carbonate, of which limestone is the most abundant (Fig. 160). Pure limestone is white or gray, but the presence of other substances gives it a variety of colors. Marble is an almost pure limestone whose crystals are very small; it is used extensively for building and for ornamental stone work.

Cement. The cement used in concrete work is made by heating a mixture of limestone and clay or shale to a temperature of 1800° F. to 2700° F. in long rotary kilns or furnaces. The fused product comes from the kilns in chunks which are ground to fine powder.

Lime. In many parts of the United States limestone rock lies close to the surface; in such localities farmers construct kilns in which they heat limestone, thus obtaining the lime needed for reducing the acidity of soil. Commercial lime, however, is manufactured in large kilns (Fig. 161). The limestone is dumped into the kiln through a door *D*. Heat produced in fire boxes *F* break up the limestone into lime and carbon dioxide. Air entering at *A* cools the lime and also furnishes oxygen for the combustion of the coal in the fire boxes. The lime drops from trap *A* into cars which run on a track under the kiln. Usually a number of kilns are operated as a unit. Lime is used in making "whitewash," mortar, and plaster. It is also used in making bleaching powder; in purifying sugar; in removing hair from hides in the process of tanning; as a disinfectant; and in reducing the acidity of soil.

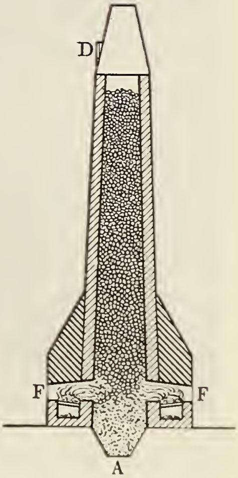
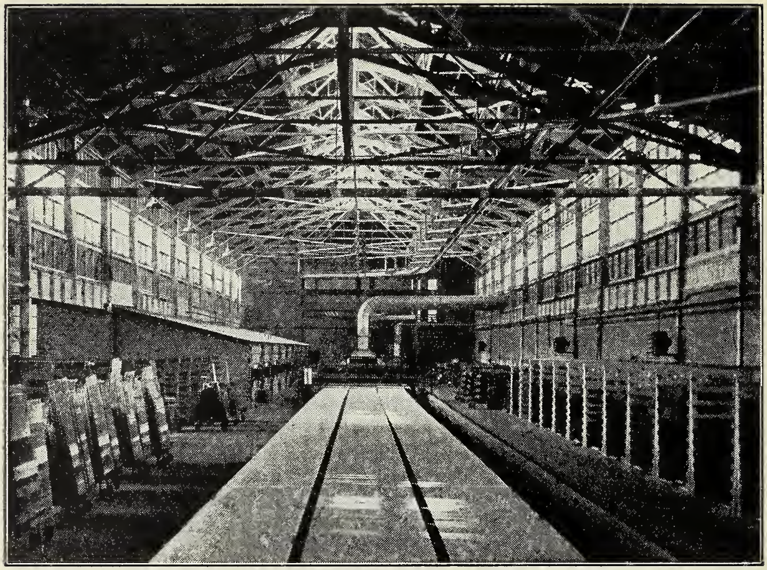


FIG. 161. A commercial limekiln.

Glass. When sand, limestone, and soda or calcium oxide are mixed and heated intensely in a furnace, the mixture slowly melts to form a transparent liquid which, when cooled, becomes a rigid, transparent solid known as *glass*.

How is window glass made? The "blowing" of window glass is an interesting process. By older methods a quantity of molten glass, which to an observer appears like molasses, is gathered on one end of a long tube (the blow pipe) by twisting the tube with one end held in the melted mass from the furnace. A glass blower then places the other end of the tube to his lips and blows, at the same time swinging the tube in an opening in the floor of the factory. He keeps blowing until the glass has formed a cylinder a foot or more in diameter. The two ends of the cylinder are then broken off, and the cylinder itself is cut lengthwise by rubbing a red hot iron rod along it until the glass cracks. Each half of the cylinder is then placed in a hot oven where it softens again and spreads out as a flat sheet of glass.

Most glass blowing today is done by machinery; hollow rods are dipped into molted glass and these slowly raised, while sufficient air is blown through the tubes to form cylinders two feet in diameter and forty feet in length.



Courtesy Pittsburgh Plate Glass Company

FIG. 162. The long strips are plate glass brought from the polishing machines on a conveyor to the storeroom. On the right are racks on which the glass is stored and on the left trucks on which smaller pieces of plate glass are moved about the storeroom.

How are other glass articles made? Bottles and many other articles are made by placing liquid glass in molds of the desired shapes, where it is "blown" by machinery operated by compressed air. Cheap glass dishes are made by pressing liquid glass in dies. Plate glass is made by casting glass into flat slabs, which are ground and polished until the surfaces are smooth and clear (Fig. 162).

Glass is colored by adding certain materials to the molten glass. Gold gives the glass a fine ruby color, while iron produces the green color which is quite common in the cheaper grades of glass.

The first glass. The oldest examples of glass work known were colored glass beads found in Egyptian tombs built more than 5,000 years ago. Its manufacture spread from Egypt to the lands surrounding the eastern shores of the Mediterranean Sea and later to Venice where, even to this day, beautiful glassware is made.

Glassmaking was established with difficulty in the Colonies because it was difficult for workers in glass to come here from the old country. The more well-to-do sent to Europe for their glassware; others did without. In America the first glass was made at Jamestown, Virginia, in 1608, by Dutch and Polish glass blowers.

"Safety" glass. To reduce the injuries caused by broken glass in bus and automobile accidents, "safety" glass is used for windows and windshields. This glass is constructed of three layers; two of glass and one of celluloid. Two thin pieces of plate glass are each covered on one side with an adhesive material. Between these a thin sheet of special celluloid is placed. The sheets of glass are held to the celluloid by the adhesive material. The three layers are then fused by heat and pressure into a clear glass plate. When glass of this kind is broken, the broken pieces do not scatter because they are held firmly by the adhesive material.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

acid
alkali
aluminum
atom
base
Bessemer converter
blast furnace
calcium
cast iron
chemical change
chloride
compound
copper
electron
element
energy
hydrochloric acid
metal
molecule
nucleus
neutralization
open hearth
oxide
phosphate
physical change
proton
salt
slag
sulfate
steel
symbol

Write the number of each item on your paper and after it the word or number that completes the statement.

1. Anything that occupies space and possesses weight is called ______ .
2. During all the changes through which a given weight of matter may pass its ________ remains unchanged.
3. The souring of milk is a ________ change.
4. When flour is made from wheat, a ________ change has taken place.

5. The smallest subdivision of an element is called __________.

6. The smallest subdivision of a compound is called a __________.

7. Substances that turn blue litmus red are called __________.

8. The number of elements is 100; 82; 92; 192; 29.

9. The number of compounds is 192; 200,000; about one million; about five million; almost without limit.

10. The number of states in which matter exists on the earth is 92; 26; 5; 8; 3.

Which of these statements are true? If any are false, re-state them in correct form.

11. The element carbon contains oxygen.

12. Brass is an element.

13. When water is changed into steam, a chemical change has taken place.

14. At ordinary temperatures all molecules are in motion.

THOUGHT EXERCISES FOR UNIT VII

Principles of Science

State the principle of science in this unit in sentence form. One of them is: Matter can neither be created nor destroyed.

Questions or Problems

1. Is the making of a salt solution a physical or a chemical change? Discuss your answer.

2. What is the difference between a compound and a mixture?

3. Name ten of the most useful elements.

4. Is water an element? Give reasons for your answer.

5. As the amount of aluminum ore in the earth is nearly twice as great as that of iron, why has aluminum been more expensive than iron?

6. Is carbon a metal? Discuss your answer.

7. What are the purposes of the blast in a blast furnace?

8. What is the difference between steel and cast iron?

9. What are alloys? Name a few and their uses.

10. What would happen to a solid gold ring if worn constantly? Why?

11. Why do many fruits have a tart or sour taste?

12. Make a list of, and give the everyday use of each of: 10 elements; 10 compounds; 10 mixtures; 5 acids; 5 bases; 5 common metals.

13. Make a list of common fruits and give the name of the acid in each?

Projects and Reports

1. By study and investigation find a substance that can be used to show that it, like water, exists in all three states of matter. Demonstrate before the class.

2. Collect materials and use them to demonstrate five physical and five chemical changes before the class.

3. Visit a blast furnace and observe the appearance of the materials used; the method of placing them in the furnace; the arrangement and purposes of pipes; the appearance of the melted iron and slag; and the method of disposing of the melted iron, etc.

4. Examine mortar or plaster carefully with a magnifying glass. Put some into an acid. Set up apparatus and devise a test to show what gas is given off. Then demonstrate before the class.

References for Reading and Study

1. Bragg, Sir William H., *Concerning the Nature of Things.* Harper and Brothers.
2. Darrow, Floyd L., *Thinkers and Doers*, Chapter IV, the Alchemist and the Chemist, and Chapter XIV, Steel. Silver Burdett Company.
3. Davies, John Langdon, *Inside the Atom.* Harper and Brothers.
4. Dietz, David, *The Story of Science.* Dodd, Mead and Company.
5. Foster, Samuel, *The Romance of Chemistry.* D. Appleton-Century Company.
6. Holmes, Harry N., *Out of the Test Tube.* Emerson Books, Inc., New York.
7. Howe, H. E., and Turner, F. M., *Chemistry in the Home.* Charles Scribner's Sons.
8. Jaffe, Bernard, *New World of Chemistry.* Silver Burdett Company.
9. Loomis, F. B., *Field Book of Rocks and Minerals.* G. P. Putnam's Sons.
10. Rogers, Frances, and Alice Beard, *5000 Years of Glass.* F. A. Stokes Company, New York.
11. Sadtler, S. S., *Chemistry of Familiar Things.* J. B. Lippincott Company.
12. Wilhelm, Donald G., *The Book of Metals.* Harper & Brothers.
13. Wisehart, M. K., *Marvels of Science*, Chapters VI, VII, XI, XII. D. Appleton-Century Company.

UNIT VIII

WHAT ARE THE FORCES OF NATURE AND WHAT USE DOES MAN MAKE OF THEM?

Exploring the Forces of Nature

Have you ever helped to push an automobile? Have you ever rowed a boat? If you have helped to push an automobile you were using force to move it. When you were pulling on the oars you were using force to move the boat. Likewise, nature exerts force upon objects on the earth's surface. One of these forces of nature causes water to flow. It causes rocks to roll down a mountain side. It holds the heavenly bodies in their orbits. Another of these forces causes particles of matter to cling together. Still another of these forces causes geysers to throw water into the air and volcanoes to erupt with terrifying violence.

As man has become more civilized, he has learned to make use of certain of these forces of nature to do his work. He has harnessed the running water of streams to run machinery and generate electricity. The same kind of force that causes geysers and volcanoes to erupt, man has been able to produce and control in such a way that it drives his trains across the continents, steamships across the seas, and the family automobile for business and pleasure.

Through past ages, vast quantities of energy have been stored up in the earth. Man's inventive genius has enabled him to release this energy and produce forces with which he can do useful work. When man is unable to use the forces of nature, he uses energy stored in the earth to produce forces which he can control and use to do his work.

Much of our comfort and happiness today has been made possible because of man's ability to use the forces of nature and release the stored up energy in the materials of the earth to produce forces with which he can do useful work.

This unit will tell you about these wonderful forces of nature, what causes them, and how man has made modern civilization possible by their use.

CHAPTER XVI

WHAT ARE SOME OF THE FORCES OF NATURE?

Do you know:

That every time you ride in an automobile you are really harnessing the sun to move you? Why you are jerked backward when a car starts suddenly? How cream can be separated from milk? Why a long range gun can shoot a shell thirty miles? Why steam can raise the lid of a teakettle?

Why glue holds two boards together? Why a stamp sticks on an envelope? Why a blotter soaks up ink? Why the moon moves in a regular path around the earth instead of flying off into space? That in a vacuum a feather would fall as fast as a cannon ball?

PROBLEM: WHAT IS FORCE? WHAT IS ENERGY? HOW ARE THEY RELATED?

What is force? We can study forces best by finding out what they do. Anything that moves does so because a *force* acts upon it. An apple falls from a tree; it is pulled downward by the force called *gravity*. Gravity draws all objects toward the center of the earth. An emery wheel, used for smoothing castings and sharpening tools, may burst because the force produced by its rapid rotation may be great enough to tear it apart. A bullet speeds from a rifle barrel because a force is developed by the explosion of powder behind the bullet in a cartridge.

If certain materials such as rubber and steel are stretched or twisted, a force within them causes them to return to their former shape. If a gas jet is opened at one side of a room, a person on the opposite side of the room will soon notice that the gas has traveled across the room; this movement of the gas is caused by a force. The sounder of a telegraph instrument or the clapper of a doorbell is moved as the result of a force caused by electricity. Oil moves up a lamp wick as the result of a force. A baseball pitcher uses force to throw a baseball to the batter. If the batter hits the ball, the direction and velocity of the ball are changed by a force. Should the batter miss the ball, it may be stopped by a force exerted by the catcher's hands.

A *force* is anything that causes (1) a body at rest to move, (2) a moving body to come to rest or to change the direction in which it is moving, or (3) a moving body to increase or to decrease its velocity.

What is energy? In the baseball illustration, the pitcher, the catcher, and the batter all exerted force on the ball, that is, all did work. In order to exert force or do work, *energy* is required. Energy is the capacity to do work.

Have you ever thought about the amount of energy required to do the work of the world? Let us consider for a moment the energy needed to drive all the locomotives used to pull trains and all the engines necessary to move ships on rivers, lakes, and oceans. Have you stopped to think that energy is necessary to heat and light our homes and the buildings used in industry? The lives and movements of people and animals are made possible only by energy. Green plants not only require energy to live but they also store vast quantities of it in food which can be used by man and animals. These are some of the well known uses of energy needed in the work of the world. Add others to the list.

The sun is the chief source of the energy that does the work of the world. This energy comes to the earth as radiant energy (heat and light). By means of air, water, and plants, this energy is made available for use on the earth. The sun evaporates water, and currents of air carry water vapor until it falls as rain, snow, and the like. Rain aids the growth of plants; it may be stored behind a dam and used to drive machinery. The energy of running water can be changed into electric energy which is used to do a large part of the world's work.

In this discussion the words light, heat, and electricity have been used. These are all forms of energy and will be discussed in separate chapters later. We shall consider next the meaning of potential and kinetic energy.

What is potential energy? Man and the lower animals have the capacity to do work because their bodies possess stored up energy obtained from food. Inanimate objects (objects without life) sometimes have capacity to do work because they possess energy which can be released. Water behind a dam, steam at high pressure in a boiler, the mixture of gases in the cylinder of a gas motor, the spring of a clock that has been wound up, and a weight that has been suspended above the surface of the earth are all examples of matter possessing stored up energy ready to be released to do work. Wood, coal, and gasoline have stored up in them energy from the sun which can be released to do work. Stored up energy is *potential energy.*

What is kinetic energy? If we let go of a suspended weight it at once begins to move downward. Why? Its motion releases its potential energy, which can now be used to do work. When water behind a dam is set free, the flow caused by gravity releases its potential energy, which can be used to do work. When steam under pressure in a boiler is allowed to expand against the piston of an engine, its potential energy is released to do work. Matter having the capacity to do work because it is moving is said to possess *kinetic energy.* Mention several other bodies that possess kinetic energy.

Can potential energy be changed into kinetic energy? Potential energy can do no work until it is released and thereby changed into kinetic energy. Steam under pressure in a boiler cannot do work until by its release it is free to move the piston of the engine, that is, until its potential energy is changed into kinetic energy. The potential energy of coal is changed into heat energy when it burns. This heat energy can be used to change water into steam. In changing water into steam, the molecules of water increase their speed; heat energy from the coal is thereby transformed into kinetic energy in the moving molecules of steam, and this kinetic energy can be used to do work. In this way the potential energy of coal has been changed first into heat energy, and then into kinetic energy. From these examples you can see that potential energy can be changed into kinetic energy. Mention several other changes from potential energy into kinetic.

Experiment 68. To show that energy can be changed from one kind into another. Make a pendulum (Fig. 163) by tying a 50-gram weight to one end of a string three feet long. Fasten the other end of the string as shown so that the weight hangs freely. Bring the pendulum to rest. What force holds the pendulum in position I?

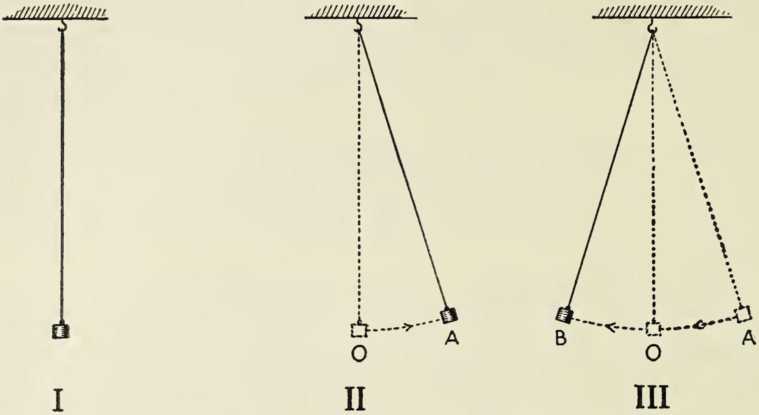


FIG. 163. Tell how a pendulum can be used to show that one kind of energy can be changed into another?

Move the pendulum so that the 50-gram weight assumes position *A* in II. When you moved the weight from *O* to *A* it received energy from your body, and in this position the weight possesses potential energy.

Now release the weight. What force acts on the weight to cause it to move from *A* to *O* in III? When the weight is moving from *A* to *O*, its potential energy is being changed into kinetic energy. At position *O* in its downward swing all of the potential energy of the weight has been changed into kinetic energy. At *O*, then, the moving weight possesses kinetic energy only. This kinetic energy raises the weight against the force of gravity to position *B* in III, and as the weight goes from *O* to *B*, its kinetic energy is changed into potential energy.

At *B* the weight again possesses potential energy only. What energy change takes place when the weight moves from *B* back to *O*? What kind of energy does the weight possess when it reaches *O* this time? What energy change will take place when the weight moves on from *O* to *A*? What force will finally bring the weight to rest?

This experiment shows that energy can be changed from one kind into another. It shows also that the energy which makes it possible for the weight to swing came from some other body. It was not created by the weight. When the energy was finally used up in overcoming the force of gravity and the resistance of the air, the weight came to rest. The energy which gave the weight the ability to swing was not destroyed. It was used in doing the work necessary to overcome the resistance of the air and the pull of gravity. You should remember from this experiment that energy can be changed from one form into another, but it can be neither created nor destroyed.

PROBLEM: WHAT IS INERTIA?

Doubtless at some time you have had the experience of being thrown forward in a car when the brakes were applied suddenly. This was due to the fact that your body tended to continue in motion after the car had stopped. Probably, you have been thrown backward when a car started suddenly because your body tended to remain at rest after the car had started. You have noticed, too, that after the power is shut off, a train tends to continue in motion for some time before it stops. An automobile is started in low gear because it requires considerable force to start it. Why is this force necessary? This tendency of matter to continue in either a state of rest or a state of motion we call *inertia*.

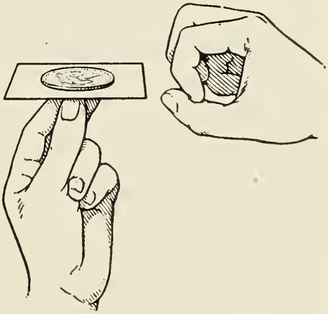


FIG. 164. What causes the coin to remain on the fingers when the card is snapped away?

Sir Isaac Newton in 1686 formulated the following statement concerning inertia and called it the first law of motion: Every body continues in its state of rest or of uniform motion in a straight line unless impelled by external force to change that state.

Problem: What Is Centrifugal Force?

If you tie a weight on a string and whirl the string around, you will feel a pull on the hand holding the string (Fig. 165). If water is poured on a rapidly rotating wheel, the water flies off because a force is throwing it away from the center of the wheel. Boys in the country have been known to amuse themselves by whirling a basket of eggs over their heads. The same force that causes water to fly from the rotating wheel, keeps the eggs from falling to the ground by forcing them away from the center of the circle in which they are swinging, and thereby holding them securely against the bottom of the basket.

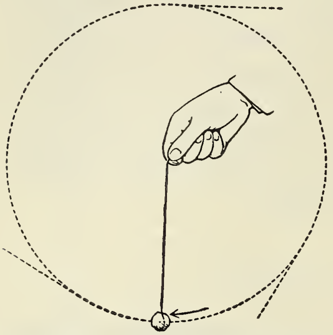


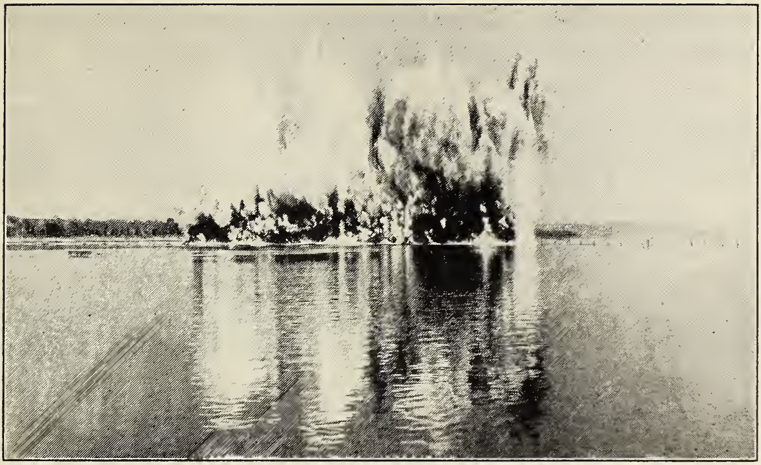
Fig. 165. Centrifugal force. What do the straight dotted lines show?

The force operating on a body moving in a circular orbit (path) and tending to cause the body to fly off in a straight line is called *centrifugal force.*

There are many ways in which centrifugal force is used in industry to do work. Laundries make use of this force to dry clothing. The wet clothing is put into a perforated, cylindrical drum. As the drum is rotated rapidly, water is thrown out of the clothes by centrifugal force produced by the rotary motion. Certain washing machines for use in the home have a similar device. The same force is used to separate oil from steel shavings in a machine shop. Cream is separated from milk in a machine (cream separator) which makes use of centrifugal force. Mention other illustrations of the use of this force.

Problem: Does an Expanding Gas Exert Force?

In Chapter XIII we referred to the great force causing the eruption of steam or other gases from the earth's interior. Because of the highly heated condition of the interior of the earth (page 210), great volumes of gases are formed. As the pressure of these gases



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 166. A picture of a blast made for the purpose of laying an oil line across the Susquehanna River near Harrisburg, Pennsylvania. It was necessary to blast out a trench in the rock underlying the river. In all, 6000 pounds of explosives were used.

increases, they finally force their way to the surface of the earth, causing tremendous eruptions of steam, water, lava, ash, and rocks. Gunpowder, nitroglycerine, and dynamite, when exploded, are also able to hurl materials through the air (Fig. 166). All explosions are due to the force exerted by rapidly expanding gases.

PROBLEM: WHAT FORCE CAUSES THE MOLECULES OF A SOLID AND A LIQUID TO CLING TO ONE ANOTHER?

What is meant by molecular force? Even though molecules of a substance are believed to be constantly in motion, they tend to cling to one another. For example, a weight of nearly eight tons may be hung on a rod of cast steel one centimeter in diameter without causing the rod to be pulled apart because the molecules of steel cling to one another. Most substances, of course, would not hold up so heavy a load, but an attractive force holds the molecules of all solids and liquids together. This attraction of molecules of the same substance or of different substances is called *molecular force.* Manifestations of this force are shown by cohesion, adhesion, elasticity, and capillary attraction.

What is the force of cohesion? Molecular force has a great deal to do with the strength of materials, and consequently with their use. If you attempt to break a stick of wood, you find that it requires a great force to overcome the attraction of the molecules of wood for each other. Tons of pressure are required to crush rocks and thereby overcome the force that holds the molecules together. The breaking of string or thread consists in overcoming the molecular forces of these substances and thereby pulling the molecules apart. This attraction of molecules of the same kind for each other is called *cohesion.* Give other illustrations of cohesion.

Experiment 69. To show the force of attraction of molecules of water for each other. Let the glass (Fig. 167) touch the surface of the water in the dish. Pull gently until the glass is pulled away from the water. Wipe the glass dry; place it on the dry surface of a table top and then pull until the glass is lifted from the table. Does it require more or less force to pull the glass plate away from the water than to pull it away from the dry table top?

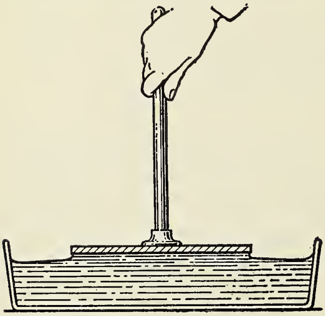


Fig. 167. The force of attraction of molecules of water for each other is less than the force of attraction of molecules of water for molecules of glass.

Touch the glass plate to the surface of the water again and lift it gently. By careful observation you can see the water in the dish is being pulled upward slightly as the glass plate is lifted. You will notice also that the bottom of the glass plate, after being pulled away from the water, is wet, showing that water molecules have been separated from water molecules and not water molecules from glass molecules. What is the force that holds the molecules of water together?

Special problem. To measure the force of cohesion that molecules of water have for each other. Arrange apparatus as shown in Figure 168. Weigh the dry plate of glass and record the weight. Next allow the under surface of the glass to touch the surface of the water and add weights as shown until the glass is pulled away from the water. Record the weight used to pull the glass away from the water. The force of cohesion will be the difference between the first weight and the second weight. Record the result. What weight was required to overcome the force of cohesion? What is the area of the glass plate in square centimeters? What was the force of cohesion acting on each square centimeter of its surface?

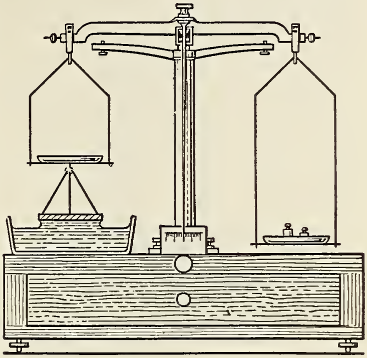


FIG. 168. Measuring the force of cohesion of water.

What is the force of adhesion? If two boards are glued together, the glue sticks to wood because the molecules of the glue and those of the wood attract each other. This attraction of molecules of different kinds for each other is called *adhesion.* We say the wood molecules hold together because of the force of cohesion, while the molecules of glue and wood cling to each other because of the force of adhesion.

It is the force of adhesion that makes paste and cement useful. A postage stamp sticks to an envelope, the envelope flap sticks to the envelope, paint sticks to wood and iron, paper sticks to the walls of our homes because of the force of adhesion. Give other illustrations of adhesion.

The force of adhesion causes a piece of glass to be wet by water. The force of adhesion between the molecules of the glass and the molecules of water is stronger than the force of cohesion between water molecules.

What is elasticity? We often call a rubber band elastic because it stretches easily. This is not the meaning of the word elasticity when used in science. *Elasticity,* in science, means the force exerted among the molecules of a substance which cause it to return to its original shape after it has been stretched or bent. It is not the ease with which a substance can be stretched or bent that determines how elastic it is, but rather its ability to return to its former shape. A steel spring is very elastic; one kind can be stretched and another compressed, again and again, and still return to their original shapes. Steel is used in making bridges because its great elasticity makes it return to its original shape after great weights have passed over it. A rubber band is only slightly elastic. What happens if it is stretched again and again. Every solid body possesses elasticity to a greater or lesser degree. Name other substances that possess elasticity.

Molecular forces in liquids. Your experience shows that a liquid will assume the shape of any vessel into which it is poured. You might think, since this is so, that a liquid does not possess molecular forces. But you have already seen in Experiment 69, however, that the force of cohesion is present in a liquid as well as in a solid and the force of adhesion causes a liquid and a solid to cling together. The action of these forces on a liquid in very small tubes or pores is called *capillarity.*

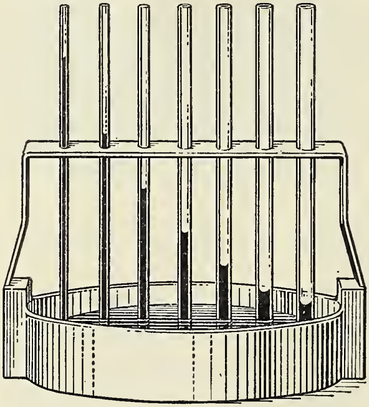


FIG. 169. Why does water rise to different heights in capillary tubes?

What is capillary attraction? The absorption of ink by a blotter is familiar to you. You have also noticed water soaking through a lump of sugar or through a sponge. If you have ever used a kerosene lamp or an alcohol burner, you may have noticed that the liquid rose up the wick. When we speak of capillarity, or *capillary attraction,* we mean this tendency of a liquid to rise in small tubes and in the very small openings of many substances.

Experiment 70. To show capillary action. Arrange a set of capillary tubes as shown in Figure 169. Color some water with red ink. Pour a little of the colored water into the basin in which the tubes stand. Observe what is happening in each tube. Has the colored water risen to the same height in all the tubes? In which tube has it risen the most? The least? Has the water risen on the outside of the tubes? What is the name of the force that causes the water to rise in the capillary tubes?

Adhesion, the force of attraction that molecules of water have for molecules of glass, is greater than the cohesion which water molecules have for each other; therefore the water wets the capillary tube and moves up the inside of the tube and also on the outside. Inside the tube the surface of the water takes the shape of an inverted hemisphere, owing to the force of cohesion of the water molecules. Capillary action is the result of the action of the two forces of attraction, cohesion and adhesion.

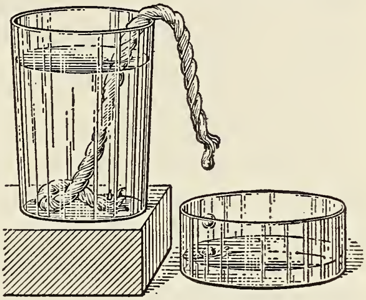


FIG. 170. Water is being drawn up through the wick by capillarity.

Experiment 71. To show capillary action in a wick. Place a wick made of twisted string in a glass of water, so that one end of the wick is in the water and the other end hangs over the edge of the glass (Fig. 170). Allow the apparatus to stand for half an hour. What happens? What force causes this action?

Experiment 72. To show capillary action with mercury. Place a piece of glass tubing in a beaker partially filled with mercury (Fig. 171). Carefully observe the surface of the mercury in the tube. Is its surface the same shape as the surface of the water in Figure 171? Is the surface of the mercury higher or lower in the tube than the surface of the mercury in the beaker? What happens to the mercury on the outside of the tube?

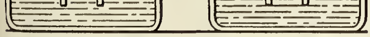


FIG. 171. Which force, adhesion or cohesion, exerts the greater attraction between water and glass? Between mercury and glass?

The effect of capillary action with mercury is just the opposite of the effect of capillary action with water. The force of attraction that molecules of mercury have for molecules of glass (adhesion) is less than the force of attraction that molecules of mercury have for each other (cohesion). Therefore the mercury does not wet the tube, and the surface of the mercury in the tube is lower than the surface of the mercury in the beaker.

PROBLEM: WHAT IS GRAVITY, AND HOW DOES IT AFFECT BODIES ON OR NEAR THE EARTH?

What is the force of gravity? Scientists tell us that every particle of matter in the universe attracts every other particle of matter. This universal attraction of particles of matter for one another is called *gravitation.*

In Chapter XI we learned that the planets move in their orbits at great speeds about the sun. For example, our earth is moving in its orbit at the rate of 18½ miles per second. Have you ever wondered why centrifugal force does not cause the planets to fly away from the sun out into space never to return? The answer is the force of gravitation. This force holds the planets in their orbits about the sun, and the moons of certain planets in their orbits. Gravitation not only controls the movements of all the planets and moons in our solar system, but also the movements of all the stars as well. Gravitation, and centrifugal force, keep all the bodies of the universe in orderly movement.

The force of gravitation between the earth and all bodies on or near the earth's surface is called the force of *gravity.* The force of gravity holds all bodies on the surface of the earth in place and tends to pull all objects above the earth back to its surface. What is the force that causes an apple to fall to the ground? Why does an airplane out of control crash to the earth? Why does not the great mixture of unconfined gases called the atmosphere leave the earth and escape into space? It is gravity that holds the atmosphere to the earth; also, it is the pull of gravity on the atmosphere that causes it to have weight and thereby exert pressure. You are probably more familiar with the effects of gravity than with the effects of any other force. Mention other effects produced by gravity.

What is weight? *Weight* is the measure of the pull of gravity exerted on any mass (quantity of matter) on the earth's surface. The pull of gravity on a pound of air or feathers is equal to the pull on a pound of lead. The pull or attraction that the earth exerts on a certain mass of one kind of material is equal to the pull exerted on an equal mass of any other kind of material.

Experiment 73. To show that gravity causes all objects to fall with the same speed. Hold two similar objects, like the quarter-pound and two-pound weights of a common balance scale, about eight or ten feet from the floor, keeping them exactly at the same height from the floor. With a pupil stationed at a convenient place to observe what happens, drop the two weights at the same instant and have the pupil observe whether the weights reached the floor at the same instant. Did they reach the floor at the same time? What pulled the weights to the floor?

The speed of falling bodies. From Experiment 73 we learned that the two weights were pulled to the floor with equal speed. Therefore the speed with which gravity pulls a body to the earth does not depend upon its weight. Were it not for the resistance of air, a feather and an iron ball would fall with the same speed.

This familiar scientific fact was not known until Galileo performed his famous experiment. Before his discovery men believed that a heavy body fell faster than a light body. Galileo dropped two balls, one of one pound and the other of ten pounds, at the same instant from the top of the Leaning Tower of Pisa, 179 feet high. The top of the tower overhangs its base by 16½ feet, consequently there is a clear drop from top to bottom. The people who were watching the experiment were astounded to see that both balls reached the ground at the same time. If you were to see such an experiment performed, you would have been convinced that gravity pulls bodies to the earth at the same speed regardless of their weights but the persons who saw his experiment were not convinced because Aristotle, one of the renowned sages of antiquity, had said that a heavy weight fell more rapidly than a light weight. The Pisans would rather believe what they had been taught or had read than the testimony of their senses.

It has been discovered, too, by experiment that a falling body not hindered by the resistance of the air travels 16.08 feet in the first second. It falls faster each succeeding second, increasing its speed by 32.16 feet per second. To find the distance a body will travel during a given number of seconds, multiply the distance traveled during the first second by the square of the number of seconds. Thus, at the end of three seconds, a body would have traveled $16.08 \times (3^2)$ or $16.08 \times 9 = 144.72$ feet.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

adhesion
capillarity
centrifugal
cohesion
dynamite
elasticity
energy
force
gravity
inertia
kinetic
mass
molecule
potential
rotate
uniform
volume
weight

Write the number of each item on your paper, and after it the word that completes the statement.

1. Every movement of matter is due to the action of a __________.
2. Water stored behind a dam possesses __________ energy.
3. __________ is the capacity to do work.
4. A bullet leaving a rifle possesses __________ energy.
5. Brakes are used on an automobile to overcome __________.
6. When an iron bar is broken the force of __________ is overcome.
7. The force of __________ makes it possible to write on a blackboard with chalk.
8. An automobile continues to run up-hill for a short time after the power is turned off because of: gravity; expanding gases; friction; ignition; inertia.
9. When glued, two boards stick together because of: elasticity; adhesion; fusion; cohesion; inertia.

Which of these statements are true? If any are false, re-state them in correct form.

10. Water drains down through the soil because of capillarity.
11. It is thought the shape of the earth is due partly to the action of centrifugal force before it became a solid.
12. The force connected with explosions is due to gravity.
13. Glass is elastic.
14. A two-pound weight will fall twice as fast as a one-pound weight.
15. Potential energy can be changed into kinetic energy.

CHAPTER XVII

HOW ARE THE FORCES OF NATURE USED TO DO WORK?

Do you know:

What force holds you on the earth? How Niagara Falls can turn the wheels in a factory a hundred miles away? What force makes a locomotive move? How the invention of the steam engine revolutionized the way in which people live?

That the gasoline engine in an automobile could not run without electricity? How an automobile makes use of the water put into the radiator? That a gasoline engine cannot run without a supply of air?

PROBLEM: HOW ARE MOVING WATER AND WINDS USED TO DO WORK?

How is gravity used to do work? Gravity can be made to do work. The operation of most machinery would not be possible without the force of gravity to draw lubricating oil down around the bearings. All kinds of drainage systems depend upon gravity to remove waste water. All devices based upon the principle of the pendulum, such as clocks, make use of gravity. The trip hammer, which breaks up concrete pavements, and the pile driver, which drives heavy timbers into the earth, depend upon gravity for their effectiveness. A man descending in a parachute is brought to safety by the force of gravity—a force that would pull him to his death if his speed were not checked by the resistance of the air to the downward motion of the parachute.

How is water power used to do work? Water power has long been used for grinding grain, for sawing lumber, for turning the wheels of machinery in factories and mills of various kinds and for many other purposes. At present its use to generate electricity is increasing rapidly, and in the future probably water power will be used more and more for this purpose. Electricity can be generated where water power is available and then carried over wires for long distances to the consumer. The water power of Niagara River is used to generate electric power for factories located near it and for cities some distance away, such as Buffalo and Rochester. The Gatun Dam of the Panama Canal furnishes water power for generating the electricity which operates the locks of the canal. The Keokuk Dam furnishes the water power which produces electricity used by many nearby cities and towns, and also St. Louis. The water power furnished by Boulder Dam and Muscle Shoals will be used to run enormous hydroelectric power plants capable of producing all the electric power needed in the surrounding regions.

The force of gravity makes water power possible. Every type of water power machinery depends upon the force of gravity for its operation, whether the water wheel which drives it is run by the weight or by the movement (kinetic energy) of water. As you have already learned, potential energy cannot do work until it is changed into kinetic energy. As long as water remains stored behind a dam it cannot do work; but when the water is released, gravity causes it to flow and its potential energy is changed into kinetic energy; this kinetic energy can be used to do work. When water power is used to generate electricity, the kinetic energy of moving water is changed into electric energy. In using the energy of rivers and waterfalls, several types of water wheels are employed.

The overshot wheel. This type of wheel (Fig. 172A) is turned chiefly by the weight of the water flowing into the buckets of the wheel. This very efficient type of water wheel is the one commonly in use in hilly regions where streams are small but have considerable fall.

The undershot wheel. This type (Fig. 172B) is much less efficient than the overshot wheel and is used in more level regions, where there is an abundance of water but little fall. The water runs through the opening, causing the wheel to turn. The undershot wheel seldom develops more than twenty-five per cent of the potential energy of the water above the dam. Under most favorable conditions, however, a modern type of undershot water wheel called the *Pelton wheel* has been run with an efficiency of more than eighty per cent. This wheel (Fig. 173) is operated by water forced through a nozzle into cup-shaped buckets of the wheel. Along Big Creek, California, Pelton wheels ninety-four inches in diameter are driven by water forced at great velocity through nozzles six inches in diameter.

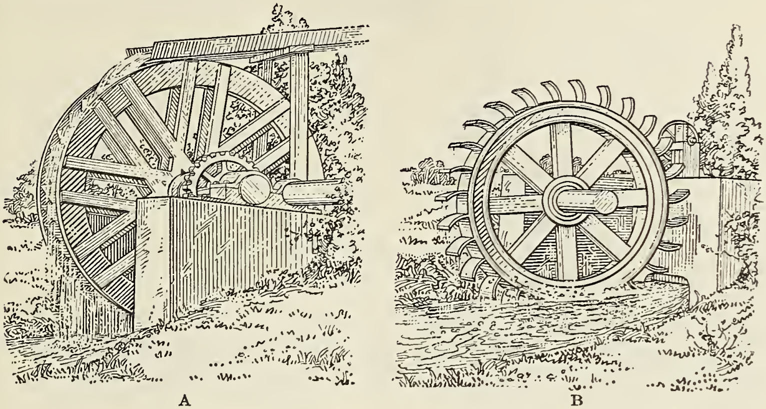

A B

FIG. 172. At the left is an overshot water wheel; at the right an undershot water wheel. Which type of water wheel do you think would be used more generally in the Middle West? In New England? Why?

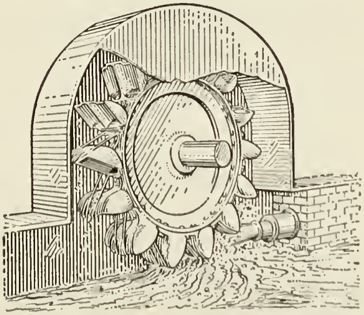


FIG. 173. Diagram of a Pelton water wheel. Is this water wheel of the overshot or undershot type?

The water turbine. This form of water wheel is now used more than any other. Figure 174 shows a water turbine used to generate electricity. It revolves in a horizontal plane at the bottom of a turbine pit. The power developed depends upon the distance water falls before it reaches the turbine and the amount of water which passes through it. The efficiency of some turbines is as high as ninety per cent. It is used exclusively at the power plants at Niagara Falls, where the pits are about one hundred thirty-five feet deep and where individual turbines develop as high as 5000 horse power (page 315).

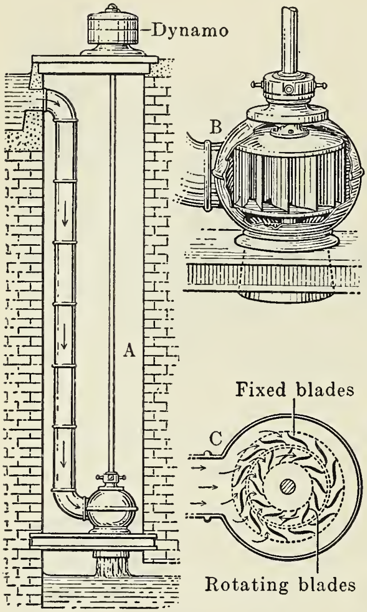


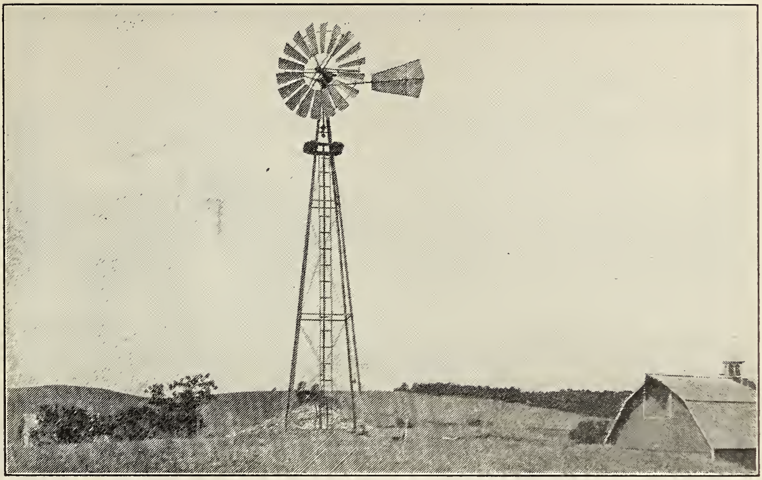
FIG. 174. A water turbine. *A* shows a turbine at the bottom of a turbine pit, also the pipe that conveys water to the turbine, and the shaft that connects the turbine to a dynamo. *B* shows the turbine with the outer casing removed so that the fixed and the movable blades can be seen. *C* is a cross section of *B*. It shows how the fixed blades direct the flowing water against the movable blades of the turbine to produce motion that "turns" the shaft and the dynamo.

How is wind used to do work? The windmill, like the water wheel, was used formerly for performing many kinds of work. It is still used in rural sections, chiefly for pumping water (Fig. 175). For many years windmills have been used in Holland to pump water from lands lying below sea level. Wind power is now being used for charging storage batteries to supply electricity in places where electric power is not otherwise available. As you have already learned, winds are currents of air. The windmill uses the kinetic energy of currents of air to do work.

PROBLEM: HOW IS THE FORCE OF STEAM USED TO DO WORK?

Experiment 74. To show that steam exerts force. Boil some water in a flask. Select a cork that does not fit the flask tightly and attempt to drop the cork into the neck of the flask while the water is boiling. The cork, no doubt, will be hurled up into the air by the force of the expanding steam in the flask.

Now place a glass tube in a one-hole rubber stopper and fit the stopper into the flask, taking care to have the lower end of the glass tube above the water in the flask. The steam will now pass out through the glass



Courtesy U. S. Dept. of Agriculture

FIG. 175. This windmill pumps water into a tank near a Wisconsin barn. How is a windmill able to make use of the force exerted by wind?

tube. Hold a small celluloid pinwheel so that the steam from the tube strikes it. What happens? What force causes the pinwheel to turn? Is there anything in the space above the water in the flask and in the tube? Can you see steam?

Why does steam exert force? In all gases the molecules move rapidly. The higher the temperature of a gas, the more rapidly the molecules move and the harder they strike against the walls of the containing vessel and against each other. Under atmospheric pressure (14.7 lb.) at sea level, water boils at 212° F. But in the steam boiler of a locomotive, where it is possible to maintain a steam pressure of 250 pounds or more per square inch, a temperature of 400° F. may be reached. This higher temperature increases the velocity of the molecules of steam, thereby storing up a vast amount of energy. The molecules of compressed steam, now moving at tremendous speed, will rush through an open passage so rapidly that much work can be done before their velocity is greatly reduced. The vast amount of kinetic energy which these molecules of steam possess causes steam to exert force and thereby do work.

Special problem. To show the operation of a steam engine. If possible, procure a toy steam engine and operate it before the class. Explain each step in its operation.

How does the force of steam run an engine? Figure 176 shows the action of steam in a steam engine. Can you explain what makes the piston move to the left and then to the right again?

To operate a steam engine the engineer opens a valve, allowing the steam in the boiler to move through a pipe to the *steam chest.* From there it flows through channel C to the end of the cylinder compartment marked B. The kinetic energy of the steam exerts a force which moves the *piston* to the left. The steam which was in compartment A is at the same time forced through channel C', and then out through the *exhaust.*

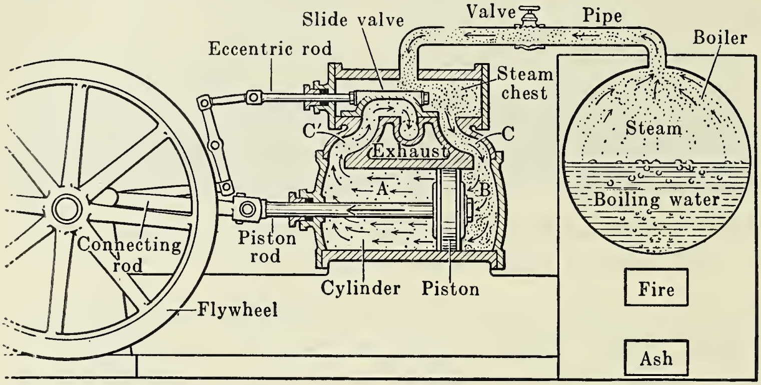
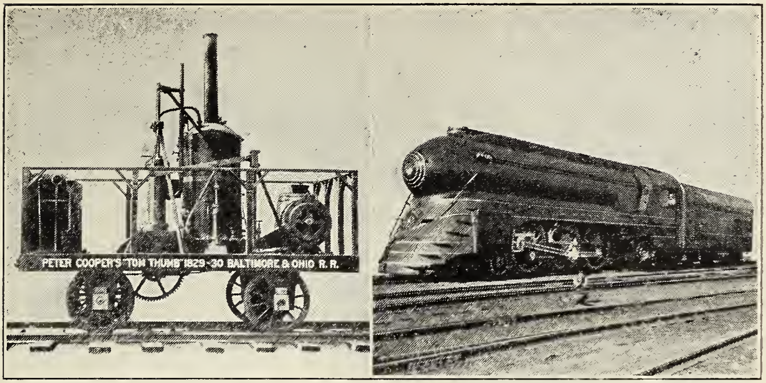


FIG. 176. Diagram showing action of steam in a steam engine of the reciprocating type. If you do not know the meaning of "reciprocating," look it up and then explain why this type of engine is given that name.

If you have observed a steam locomotive, you have noticed above the *connecting rod* a smaller rod moving back and forth. This is the *eccentric rod,* which moves the *slide valve* shown in the diagram. This slide valve is so constructed as to admit steam first into channel C, then into channel C'. When the piston moves to the left, the eccentric rod moves the slide valve to the right at the proper time, connecting channel C with the exhaust but opening channel C' to the steam chest. This allows steam to



Courtesy Baltimore & Ohio Railroad

FIG. 177. Compare the first American locomotive, "Tom Thumb," built by Peter Cooper in 1829 for the Baltimore & Ohio Railroad, with a modern locomotive, "The Royal Blue," built for the same railroad.

pass through channel C' into compartment A, forcing the piston to the right, and forcing the used steam from compartment B through channel C out through the exhaust. Again at the proper time, the eccentric rod returns the slide valve to the left. Thus we have followed the steam into the cylinder and out again while the *fly wheel* operated by the connecting (driving) rod makes one complete revolution.

The driving wheels of a steam locomotive are caused to revolve by a steam engine, a part of the locomotive.

A stationary engine transmits its power to machinery either by a belt attached to its driving wheel directly or by a separate pulley on the same shaft with the fly wheel.

What changes have been made in industry by the use of the steam engine? The steam engine was invented in 1768 by James Watt, an instrument maker for the University of Glasgow. By 1785 the steam engine had been greatly improved and was being introduced into factories in England. This invention caused a profound change in the industrial life of the world. Although by the middle of the eighteenth century political and social reforms had been effected in many countries, industrial arts were still being carried on in practically the same way they had been six or seven thousand years before in Egypt and Babylonia. In the century and a quarter following Watt's invention, however, revolutionary changes were made in industrial arts. Hargreaves invented the spinning jenny used in spinning thread; and the next great need, a machine for weaving the thread into cloth, was supplied by Cartwright's loom, for which James Watt's improved steam engine supplied the power. The application of the steam engine to transportation needs gave to the world the steam railroad (Fig. 177) and the steamship. These three inventions, the spinning jenny, the power loom, and the steam engine, started an industrial revolution in which machine work has steadily been replacing handwork. They have made possible our great industrial developments of today. It is significant that the steam engine was developed in England where there are few streams which could be used for water power.

The steam turbine. This is the latest type of steam engine. It is used in great ocean liners, in power plants, and wherever a vast amount of steam power is needed. It furnishes steam power at a more uniform rate than the older type of engine. It is lighter, and thus requires less expensive foundations. Furthermore, it occupies just about one tenth of the floor space covered by the older type of engine of the same power.

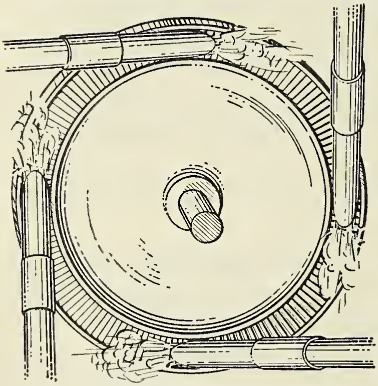


Fig. 178. How do jets of steam from the nozzles turn the wheel of this steam turbine?

The steam turbine operates in a manner similar to the water turbine or the windmill (page 296), but the shaft is turned by steam directed through nozzles against the blades of the wheel (Fig. 178). The kinetic energy or force of the steam causes the wheel and shaft to revolve at a very high rate of speed. The steam can be used several times by arranging a number of turbines in series so that the steam passes from one turbine wheel to another (Fig. 179). One of the great turbines of the ocean liner Berengaria contains 50,000 blades and develops 22,000 horse power.

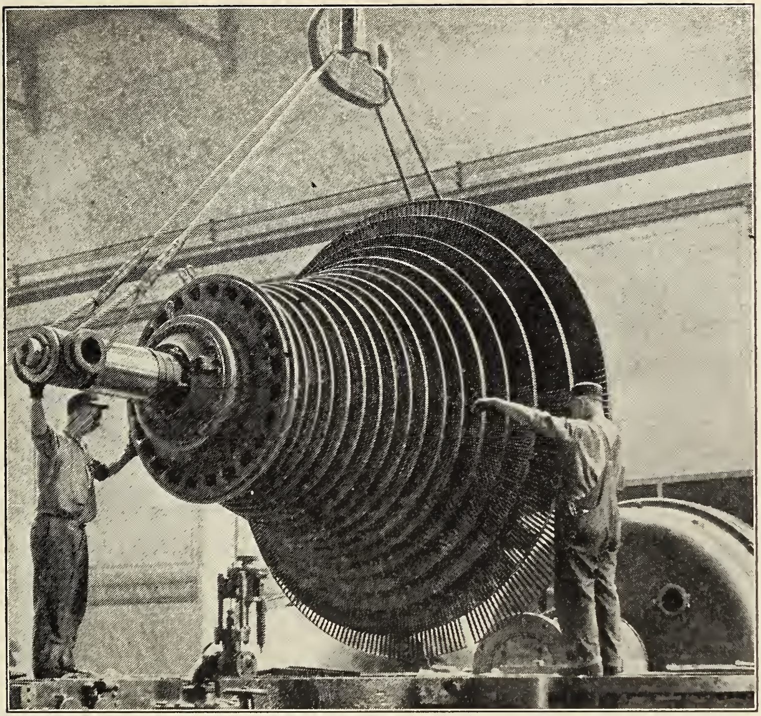


FIG. 179. The rotating part of a steam turbine. The energy of steam acts first upon the blades of the smallest wheel, then upon the blades of larger and larger wheels in turn until the energy is nearly all used.

PROBLEM: HOW IS THE FORCE OF EXPANDING GASES USED TO DO WORK?

The gasoline engine. The gasoline engine is used in automobiles, trucks, tractors, motor boats and airplanes. It can be operated also as a stationary engine for a variety of purposes such as pumping water, mixing concrete, and grinding grain. Because it is less expensive, costs less to operate, and is more easily moved from place to place, it is more widely used than the steam engine. In the future there will probably be a much wider use of the gasoline engine.

When a gasoline engine is running, use is being made of the force of expanding gases. As you know, when gasoline vapor is mixed with air and ignited by a spark or flame, a violent explosion takes place. The liquid gasoline is passed through a device called a *carburetor*, where it is changed from a liquid into a gas and at the same time mixed with air. This mixture of gasoline vapor (gas) and air is forced into the combustion chamber, where it is ignited and the force of the expanding gas caused by the explosion of the mixture is used to run the engine.

How does the force of expanding gases run a gasoline (gas) engine? In explaining the operation of the gas engine we will follow step by step the operations within one cylinder. A *cylinder*, as the name indicates, consists of a cylindrical casting, one end of which is closed with the exception of two valves, one for the intake of gas and the other for the exhaust. Moving up and down within the cylinder is a piston (Fig. 180).

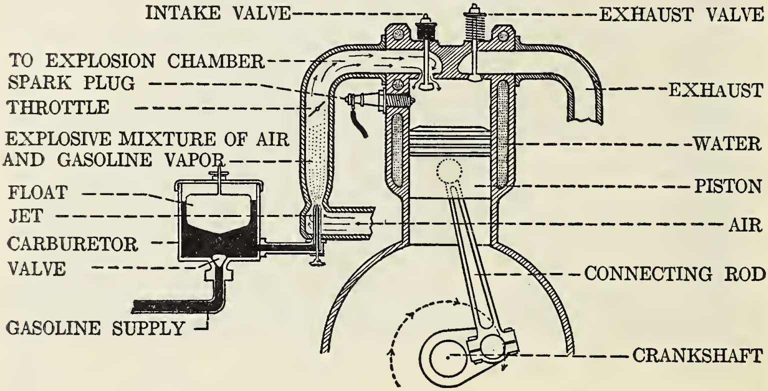


FIG. 180. One cylinder and carburetor of a gas engine.

Practically all automobiles today are propelled by four-stroke, or four-cycle, engines; that is, there are four strokes of the piston for each explosion in the cylinder.

The first stroke (Fig. 181A) is the *suction* (or *intake*) *stroke*, during which the piston moves downward, creating a partial vacuum in the cylinder. To fill the partial vacuum a mixture of air and gasoline vapor from the carburetor is forced by air pressure through the intake valve into the top of the cylinder. The second stroke is the *compression stroke.* During this stroke both valves are closed, and the piston moves upward and compresses the mixture of gases.

In the third stroke, called the *power stroke,* both valves remain closed. After the mixture of gases has been compressed, an electric spark produced between the two points of the spark plug explodes the mixture of gases, and the force of expanding gas sends the piston down with great force. During the fourth stroke, called the *exhaust stroke,* the piston moves upward and the valve *V′* opens. The upward motion of the piston forces the burned gases out through the valve *V′* and an exhaust pipe containing a muffler.

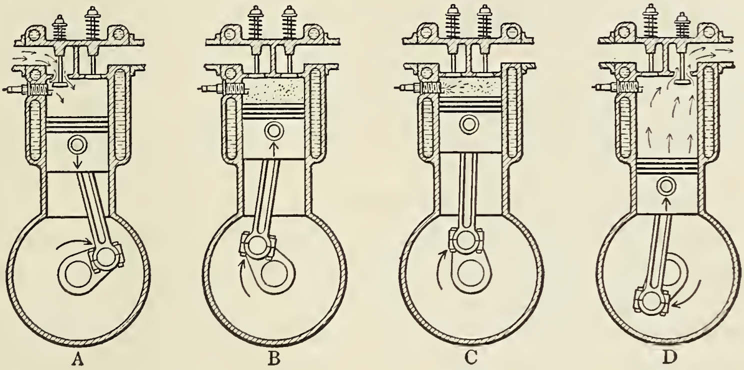


FIG. 181. Trace the action of a four cycle engine through the intake stroke, *A;* the compression stroke, *B;* the power (explosion) stroke, *C;* and the exhaust stroke, *D.*

During the operation of the four strokes of a gasoline engine the potential energy of gasoline is converted into kinetic and heat energy. In the power stroke the potential energy possessed by the gasoline is changed into kinetic and heat energy by the explosion of the mixture of gasoline and air. The heat and kinetic energy liberated by the explosion of the mixture of gases forces the piston down in the power stroke; also, some of the energy heats the engine. Thus we see that the potential energy of gasoline has been changed into the kinetic energy of a highly heated gas which was used to do work by forcing the piston downward. Part of the heat heats the engine.

In order to remove the heat from the engine so that it will not become overheated, a cooling system is necessary. The cooling system usually provides a circulation of water through a radiator and around the cylinders by means of a water pump. As the water circulates, it takes heat from the engine; and as it passes through the radiator, it loses heat. The fan causes a blast of air to move through the coils of the radiator, thus cooling the water. Do you know an automobile that has an air-cooled engine? How are airplane engines cooled?

The first gasoline engines had only one cylinder, and it was necessary then to use a heavy wheel called a *flywheel* to carry on the movement of the crankshaft between successive power strokes of the piston. Today, in addition to a flywheel, automobiles have a number of cylinders which are fired rapidly one after the other, thus producing a smooth, even flow of power.

Gas engines may use other fuels than gasoline. Both gasoline and kerosene are used in tractors. Highly refined fuels are prepared for airplanes and airships. The gas engine has a number of advantages over the steam engine, due largely to the kind of fuel used. Besides, the gas engine is nearly twice as efficient as the steam engine, and relatively much lighter.

Dust explosions. We have already studied that an explosion can be caused by igniting gasoline vapor that is mixed with air. When the forces of expanding gases of an explosion are controlled, they are of use to man. When they are not controlled, they may cause loss of life and destruction of property. We ordinarily think of destructive explosions as being caused by gasoline, natural gas, steam, gun powder, dynamite, nitroglycerine, and other explosives.

Few of us know that dust may cause destructive explosions. About twenty destructive dust explosions occur in our country each year in such places as grain elevators, flour mills, feed and tobacco factories, starch and malt storage houses, woodworking and paper mills, spice and cocoa factories, and in plants which handle such materials as powdered aluminum, powdered milk, powdered soap, and cottonseed meal. Dust explosions have been caused in apartment houses by dust from vacuum cleaners, or flour which has been poured down incinerator pipes.

Certain kinds of dust mixed with air need but a spark to explode. This spark may be caused by overheated bearings of machinery, stones or pieces of metal striking pieces of metal, sparks from electric starting switches, static electricity generated by moving machinery, or by the careless handling of matches. Insurance companies recommend for protection against dust explosions such precautions as the installation of adequate dust collecting and ventilating systems, the use of dust proof lamps, the installation of an alarm system that indicates when a bearing is overheated, the placing of electric wires in conduits, and the grounding of all electric machines.

As stated above, not all destructive explosions are caused by dust. Coal and natural gases may escape into a building and be ignited by a spark. Such disasters have occurred and have caused the loss of many lives. The origin of the spark has frequently puzzled investigators of these explosions. We can readily understand the necessity of care in the installation of all electric equipment, and in the use of matches or other sources of open fires where there may be danger of explosions.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

carburetor
Cartwright
circulation
compression stroke
crankshaft
cylinder
eccentric rod
exhaust stroke
flywheel
gasoline engine
Hargreaves
intake
kerosene
lubricating
overshot wheel
Pelton wheel
piston
radiator
revolution
slide valve
steam chest
steam turbine
undershot wheel
valve
vapor
water turbine
Watt

Write the number of each item on your paper, and after it the word that completes the statement.

1. A water wheel is operated by the force of ———.

2. A special water wheel operated by water forced through a nozzle into cup-shaped buckets is called a ________ wheel.

3. The rod on a steam engine used to move the slide valve in the cylinder is called the ________.

4. The latest type of steam engine is the ________.

5. In the operation of a gasoline engine the gasoline is forced through the carburetor by ________.

6. In a gasoline engine the mixture of gases in each cylinder is exploded by a device called a ________.

7. The strokes of a four-cycle gas engine in their proper order are: compression; exhaust; intake; explosion.

8. An example of an internal combustion engine is a: gasoline engine; steam engine; compressed air engine; electric motor; steam boiler.

Which of these statements are true? If any are false, re-state them in correct form.

9. Steam is a visible gas.
10. Molecules of all gases move about rapidly.
11. A steam turbine has a piston.
12. The steam engine made the invention of the airplane possible.
13. Electricity is necessary for the operation of a steam engine.
14. The flywheel of a gasoline engine is attached to the cam shaft.
15. The exhaust valve is open during the compression stroke.

THOUGHT EXERCISES FOR UNIT VIII

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Energy is the capacity to do work.

Questions or Problems

1. Why would you weigh less on Mars than you do on the earth?

2. Why is it difficult to stand still in a car when it is starting or suddenly coming to a stop?

3. What property of matter enables us to blow soap bubbles?

4. Why does an automobile skid?

5. How did the invention of the gasoline engine affect the success of air transportation?

6. How is gravity necessary in the operation of a turbine water wheel?

7. What property of matter makes it necessary to shift gears on an automobile?

8. Could an automobile run in a vacuum under its own power? Give reasons for your answer.

9. How does inertia aid in the operation of a gas engine?

10. Why is it necessary to have a flywheel on an automobile engine?

Projects and Reports

1. Collect materials and apparatus to demonstrate before the class the forces of gravity, centrifugal force, force of expanding gas, adhesion, elasticity, and capillarity.

2. Study the life of Galileo and note especially some of his experiments on falling bodies. Can you demonstrate one of these before the class?

3. Make a water wheel, either old type or turbine, and arrange apparatus for its operation before the class.

4. Study the life of James Watt and report to class. List some of his later inventions which improved the steam engine.

5. Study the engine in your automobile. Discuss the force that moves the pistons. How does gravity aid the operation of the cooling and lubricating systems? How is inertia used to advantage?

6. If there is in your locality an electric plant run by water power, visit it and find out the following: length of dam, height of dam from river bed, number of turbines, etc.

7. Study the construction and operation of a Diesel engine. How does it differ from the ordinary engine?

References for Reading and Study

1. Clarke and Small, *The Boys' Book of Physics*, Chapters IV and X. E. P. Dutton and Company.

2. Darrow, F. L., *Thinkers and Doers*, Chapter II, Galileo; Chapter V, James Watt. Silver Burdett Company.

3. Kuns, Ray F., *Automotive Essentials*. The Bruce Publishing Company, Milwaukee.

4. Lynde, C. J., *Everyday Physics*, Chapters III and XXII. The Macmillan Company.

5. Meister, Morris, *Energy and Power*. Charles Scribner's Sons.

6. Mott-Smith, M. C., *The Story of Energy*. D. Appleton-Century Company.

7. Reck, Franklin M., *Automobiles from Start to Finish*. Thomas Y. Crowell Company, New York.

UNIT IX

HOW HAVE MACHINES MADE THE WORK OF MAN EASIER?

Exploring the World of Machines

Since the earliest time, the genius of man has been used to improve his surroundings, to overcome the forces of nature that threatened him, and to harness them for his use. His muscles were weaker and his movements were slower than those of most lower animals, but his wit was very much quicker. In time, he came to rule the world because his quick wit made it possible for him to make tools and to transmit the knowledge which he had gained through his experiences to his children.

When he used a club to strike a blow more effective than the blow he could strike with his bare hands, he gained in power; when he used this same club as a lever to raise heavier weights, when he chipped a stone to form a wedge for cutting purposes he was gaining more power.

Much later on, he discovered that he could use the trunks of small trees as wheels on which to roll heavy objects and that this wheel could be used as a pulley to raise weights. The wedge of stone when much enlarged became an inclined plane which enabled him to change more readily the position of heavy objects. When the inclined plane was curved, it became a screw which increased his power still more. Thus gradually man came to possess and use six simple machines—the lever, the wheel and axle, the pulley, the wedge, the inclined plane, and the screw. The one principle upon which the operation of these machines depends makes possible the most complicated machinery of today.

The development and uses of these simple machines enabled him to acquire many comforts which his ancestors were not able to enjoy. As these machines came into more general use, he learned to use the power of animals to make them more effective and thus to save his muscular energy. Later he learned to place paddles in streams to catch the energy of the moving water; to hang sails to catch the energy of the wind, and in more recent times he learned to use the energy of heat, of escaping steam, and of electricity to operate more complicated machines, the ones that now do the work formerly done by many men and animals.

You know that today you are living in an age of complicated machines. This unit will tell you how these machines have been developed and show you how they are used to do the useful work of man today.

CHAPTER XVIII

HOW DOES MAN USE MACHINES TO DO WORK?

Do you know:

That if you push on a wall as hard as you can you are not doing any work, but that if you move the smallest grain of sand you are doing work? How much work a thirty horse-power engine can do? Why you can lift a car with a jack? That every time you use a knife or fork you are using a machine?

How you could lift a grand piano without help? Why Archimedes claimed that he could move the earth if he had a place on which to stand? Why screws are used in furniture instead of nails? Why no machine can be 100% efficient? Why it is necessary to oil all machines that have moving parts?

PROBLEM: WHAT IS WORK AND HOW IS IT MEASURED?

Why must work be done? Work is required to supply the necessities of life. Food is one of our urgent necessities. If comparatively few people lived in our country, as was true before white men came, food could be obtained largely by hunting and fishing. But the present population of the United States is so great that most of us would soon starve if millions of people not only in our country but in other countries were not working to produce and prepare our food. Soil must be cultivated, seed sown, and crops harvested and distributed. Among our foods are tea from Japan, coffee from Brazil, fruit from Florida and California, grain from the Northwest and Canada, meat from the Middle West, and dairy products from New York, Wisconsin, and other states.

Another army of workers is engaged in supplying materials and labor to erect the buildings in which we live and work (Fig. 182). Lumber is cut, sawed, and finished for the builder's use. Stone is brought from quarries and cut. Bricks are manufactured

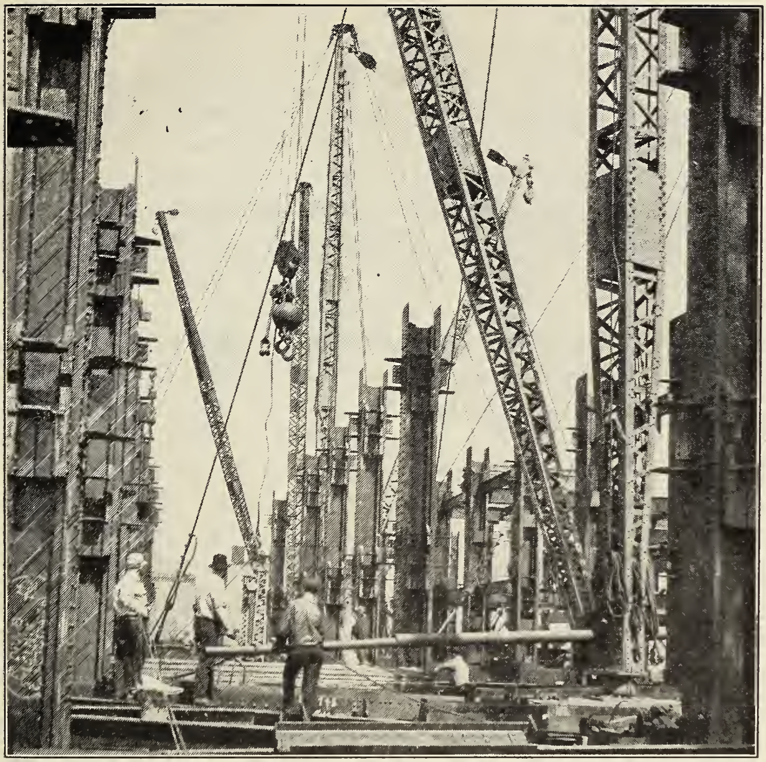


Photo L. W. Hine *Courtesy Empire State Building, Inc.*

FIG. 182. Skilled workers, aided by machines, are needed to construct a large building. The men and machines shown are at work upon the Empire State Building. Point out several kinds of machines. What holds the steel girders together? Notice that the girders are numbered to indicate where they should be placed.

from clay. It would be difficult to make a list of all the kinds of work required to produce hardware and plumbing supplies alone. Another great host of workers is supplying materials used to paint and decorate our houses.

It is equally difficult to list all the kinds of occupations needed to supply our clothing. In colonial days flax and wool were spun, cloth was woven and dyed, and made into garments, all within the home. But times have changed. Today thousands of workers are engaged in growing cotton and flax, in raising sheep for wool. Many others are engaged in the production of silk, both natural and artificial. Other thousands are engaged in manufacturing these textiles into cloth and still other thousands in making garments from the cloth. A large number of men are employed in trapping or raising animals for furs and in preparing their pelts for the market. Many other workers are engaged in the preparation of hides for leather and in the manufacture of shoes.

To the workers who supply our food, shelter, and clothing, we must add those employed in furnishing instruments, tools, and machinery for communication, agriculture, and manufacturing—the miners, toolmakers, machinists, wood workers, structural steel workers, glass workers, foundry men, metal workers, painters, and all the others—and we are fairly astonished at the extent of the work required to supply our needs.

At all times civilization is undergoing changes. These changes come so gradually that they are scarcely noticeable from one year to another; but if we consider a period of ten or twenty years, we realize that changes have taken place. One of the chief causes of the changes that have come in the past century is the development of machines. In the civilization of today much work is done by machinery. Of course in some remote parts of the world—such as part of India, the interior of Africa, and certain parts of South America—we find that most of the work is still done by beasts of burden and by human labor. In these lands civilization is considered to be behind the civilization with which we are familiar.

In this chapter, we shall learn in part how machines aid man in his work.

What is work? Whenever *work* is done, a weight is moved or a resistance is overcome. If you are spading in the garden, you are doing work because you are moving soil, which has weight. The boy who is delivering groceries is doing work because he is carrying a weight. When you carry your book, you are doing work because you are moving a weight. A steam engine that starts a train of cars or runs machinery is doing work because it is overcoming resistance. Although we sometimes speak of mental activity as work, from the point of view of science it is not work. No work is performed unless a resistance is overcome or a weight is moved.

How is work measured? Man has devised units for measuring distance, such as the inch, foot, yard, and mile; and for measuring weight, such as the gram, ounce, pound, and ton. Man has also devised a unit for measuring work.

Experiment 75. To show how work is measured in the English system. Place a one-pound weight on a table beside a yardstick held vertically (Fig. 183). Lift the pound weight one foot. You have done one foot-pound of work, measured in units of the English system.

1 pound × 1 foot = 1 foot-pound.

Had you lifted the weight two feet, you would have performed two units of work:

1 pound × 2 feet = 2 foot-pounds.

If you had lifted two pounds through a distance of one foot, you would also have performed two units of work:

2 pounds × 1 foot = 2 foot-pounds.

In lifting five pounds through a distance of four feet, you perform twenty units of work:

5 pounds × 4 feet = 20 foot-pounds.

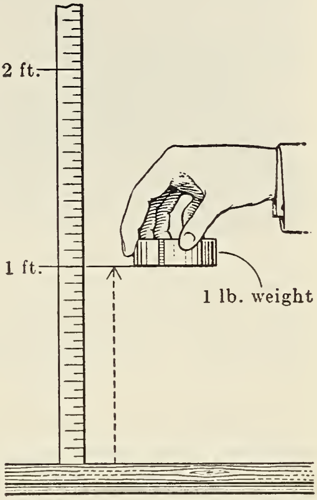


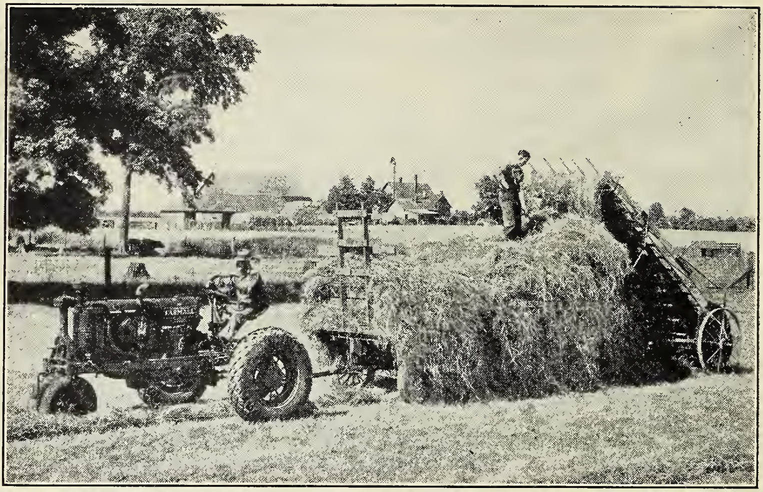
FIG. 183. In lifting a weight of one pound, a distance of one foot, how much work is done?

Measured in the English system the amount of work done on a body is always equal to the force in pounds multiplied by the distance in feet through which the force moves the body. In the English system the unit for measuring work is the *foot-pound*.

Experiment 76. To show how work is measured in the metric system. Place a gram weight on the table beside a meter stick. Lift the gram weight one centimeter. You have done one gram-centimeter of work, measured in units of the metric system.

1 gram × 1 centimeter = 1 gram-centimeter.

If you had lifted a 10-gram weight 10 centimeters from the table, you would have performed 100 gram-centimeters of work.



Courtesy Allis Chalmers

FIG. 184. Man can increase his power to do work by improving his tools. How does this method differ from the method formerly used for doing this work? Has man improved his tools in this instance? Has he increased his power to do work?

Measured in the metric system the amount of work done on a body is always equal to the force in grams multiplied by the distance in centimeters through which the force moves the body. In the metric system the unit for measuring work is the *gram-centimeter*.

In both units of work, the foot-pound and the gram-centimeter, there are two factors: (1) the force, and (2) the distance through which the force moves a body or through which a resistance is overcome.

Special problem. In shoveling a ton of coal into a coal bin, it was necessary for Mr. Gibson to raise each shovelful of coal five feet. Not counting the weight of the shovel, how many foot-pounds of work did he perform?

How is power measured? *Power* is the rate of doing work. A boy might be able to unload a carload of apples in 8 hours, but, if a man is able to do the same work in less time we say that the man is able to exert more power than the boy. With a team of horses a farmer uses a disk or a harrow one at a time; with a tractor (Fig. 184) he can use larger ones of both at a time. We say, therefore, that a tractor can exert more power than a team of horses because with it the farmer can disk and harrow his field in less time. The tractor's rate of doing work is faster than the team's rate.

What is meant by horse power? In the time of James Watt (1736–1819) the horse was a common beast of burden and source of power. Watt estimated that a horse, walking at the rate of three miles an hour and raising 125 pounds by means of a rope and pulley, would perform 33,000 foot-pounds of work in a minute, that is, 550 foot-pounds per second.

One *horse power* is the ability to do 33,000 foot-pounds of work in one minute, that is 550 foot-pounds of work a second. Although this estimate was found later to be a little too high for the amount of work the average horse could do, the figures have been adopted as the measure of horse power.

As power is the rate of doing work, the two factors in power are (1) time and (2) work. The unit of time is the second and the unit of work is the foot-pound.

Power may be found by dividing the number of foot-pounds of work done by the time in seconds required to do the work, that is:

$$\text{Power} = \frac{\text{Work (in foot-pounds)}}{\text{Time (in seconds)}}; \; P = \frac{W}{T}$$

Since 1 horse power equals 550 foot-pounds per second, we can express power in horse power by dividing the power (foot-pounds per second) by 550.

To illustrate, find the horse power of an engine capable of developing 33,000 foot-pounds of work in 2 seconds. Dividing 33,000 by 2, we find that the engine can develop 16,500 foot-pounds of work in 1 second. 16,500 divided by 550 is 30. Hence, the engine is a 30 horse-power engine.

Steam locomotives range in power from 500 to 5000 horse power, while engines (steam turbines) in steamships develop as high as 20,000 horse power.

Special problem. How many foot-pounds of work per second can be performed by an engine developing 25 horse power?

Problem: What Are the Simple Machines, and How Are They Used to Do Work?

How did modern machinery develop? In the early history of the human race man depended chiefly upon his hands to secure food and to erect a shelter. Later on he learned the advantage of using clubs, spears, and other weapons to kill the beasts that he ate for food. In moving stones and boulders, he discovered that he could exert greater power by using a pole to pry with. He also discovered early that, by placing heavy objects on rollers, they could be moved much more easily than by dragging them on the ground; from the use of rollers he advanced to wheeled vehicles, such as carts and chariots. These were probably the first crude machines. A *machine*, then, is a device to aid man in doing work.

Work is often done by the use of a very simple machine. For example, the man who desires to lift a weight of 1000 pounds a short distance may do so easily with the aid of a lever. If he wishes to raise materials to the top of a building, he may do so by means of a rope and pulley. If he is loading heavy barrels on a freight car, he can do so by rolling them up an inclined plane. If he is lifting a building from its foundations, he uses a jackscrew. As you have probably noted, all these simple machines not only make easier the work which a man might be able to do unaided, but they also enable him to do much more work.

From tool marks on rocks and from remains that have been discovered we have been able to learn what kinds of tools were used by man before the time of written records. The life of man on the earth has been divided, according to the tools used by him at different periods, into three ages: the Stone Age, the Bronze Age, and the Iron Age.

The Stone Age. The first men of whom we have any record used rough stones for weapons and tools. For many thousands of years these rough stones served for axes and for spear heads and arrow heads (Fig. 185). Later in the Stone Age, men began to polish certain stones so as to make tools that were smoother and sharper. Pieces of flint were chipped from rocks and the edges polished and sharpened by rubbing them against other rocks or with sand. In our own country, stone tools were made by the Indians.

If a piece of flint can be secured, try chipping it into various shapes and sizes as men did in prehistoric times. If you try this, you will realize that early man must have acquired considerable skill in order to make his tools.

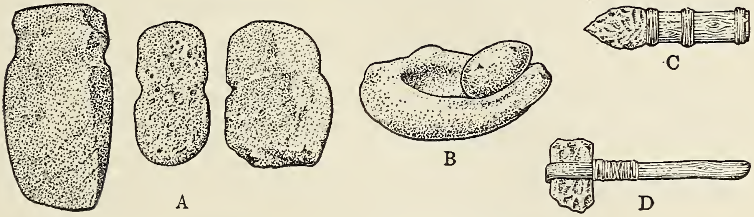


FIG. 185. Early implements of industry and defense: *A*, axeheads; *B*, a grinding outfit; *C*, a spear head; *D*, a crude hatchet.

The Bronze Age. Man found in time that when certain rocks were melted, metals were obtained from them. He found that better tools could be shaped from this metal than could be made from even the smoothest stones. The metal which he secured in this way was a mixture of copper and tin which we now call bronze. Thus the Stone Age was succeeded by the Bronze Age. During the Bronze Age household utensils as well as tools and weapons were made from this metal. The workmen of the time became quite skilful in shaping bronze into artistic forms.

The Iron Age. The Age of Bronze was followed by the Iron Age. As man learned to use fire more skilfully, he was able to extract iron from its ores and to make it into tools and weapons much harder and with sharper edges than had ever been made before. We are still in the Iron Age, and our tools and machinery are constantly being improved. The present period of the Iron Age, which began with the introduction and wide use of complex machinery, is sometimes called the "Machine Age."

What are the simple machines? In going through a large printing plant or machine shop, or even in observing an automobile engine, one is amazed at the complexity of modern machinery. Yet if you were to analyze the most complex machine, you would find that it was constructed by combining a number of simple machines. There are but six simple machines: the lever, the pulley, the wheel and axle, the inclined plane, the screw, and the wedge. All other machines are combinations of two or more of these six simple machines.

The lever. A bar arranged to turn on a point (pivot) so that it can be used to help man do work is called a *lever*. If you observe the handle of a lift pump or the steel bar used in operating the emergency brake of an automobile, you will find that each is a lever which may be moved by a force applied to one end. Near the other end is a point called the *fulcrum*, where the lever turns on a pivot or bearing. In most levers the point where the work is done is a short distance beyond the fulcrum. In using levers like the crowbar and the wheelbarrow, work is done because weights are lifted and resistance is overcome. In using levers like nut crackers, scissors, and grass shears, work is done because resistance is overcome.

Experiment 77. To develop the law of the lever. Suspend a meter stick at its center (Fig. 186) so that it balances. Hang a 50-gram weight on the stick at the 54 centimeter mark, and a 20-gram weight at the place on the stick where it will balance the 50-gram weight. How far is the 50-gram weight from the fulcrum (point of suspension)? How far is the 20-gram weight from the fulcrum? Multiply 50 by the number of centimeters the 50-gram weight is from the fulcrum; multiply 20 by the number of centimeters the 20-gram weight is from the fulcrum. How do these products compare?

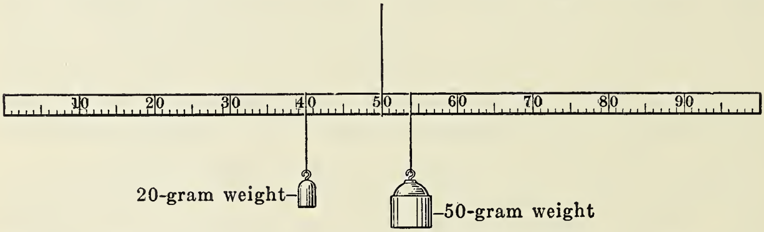


Fig. 186. The law of machines is illustrated by the operation of a lever.

Repeat the experiment, placing the 50-gram weight on the 58 centimeter mark; the 62 centimeter mark. How do the products compare in each case?

From this experiment we conclude that the product of the weight and its distance from the fulcrum of the lever is equal to the product of the other weight and its distance from the fulcrum. The distances from the fulcrum to the points where the weights act are called the *arms* of the lever.

Hence we have W (one weight) × L (the length of one arm) = w (the other weight) × l (the length of the other arm), that is:

$$WL = wl$$

Special problem. A 6-foot crowbar is placed so that the fulcrum is one foot from one end. If a man presses down on the other end with a force of 150 pounds, what weight can he raise?

With the same force applied and the same crowbar, what weight can the man raise if the fulcrum is 6 inches from the weight end?

Experiment 78. To develop the law of machines. Suspend a meter stick at its center so that it balances. Place the 20-gram weight on the 25 centimeter mark and the 50-gram weight on the 60 centimeter mark. Let the 20-gram weight represent the force; the 50-gram weight, the weight to be lifted; and the support of the meter stick, the fulcrum. With the meter stick in a position parallel to the table top measure the vertical distance each weight is above the table. Move the meter stick so that the 20-gram weight (the force) is lowered 10 centimeters. Measure the distance the 50-gram weight (the weight) was lifted. Record this distance.

If you have performed the experiment accurately, you have found that when the force was moved 10 centimeters, the weight was lifted 4 centimeters. The force (F) multiplied by the distance (D) through which it moves equals the weight (W) multiplied by the distance (D') through which it moves.

$$\text{Then, } 20 \times 10 = 50 \times 4$$
$$200 = 200$$

or

$$F \times D = W \times D'$$

Compute these products when the weights are in other balanced positions along the meter stick. How does each set of products compare?

What is the law of machines? In the experiment just performed the force of 20 grams which operated the lever moved through 10 centimeters. This means that the force did 20 × 10, that is, 200 gram-centimeters of work. This movement caused the weight of 50 grams to move 4 centimeters, that is 50 × 4 or 200 gram-centimeters of work were done on the weight. This fact, that the amount of work done on a machine equals the amount of work done by the machine, is called the *law of machines.*

While you have developed this law by experimenting with a lever, it holds for all machines.

The law of machines may also be stated:

The force multiplied by the distance through which it moves is equal to the weight or resistance multiplied by the distance through which it moves.

It may also be stated by the formula: $FD = wl$.

In solving problems with this formula, you must be careful in your choice of units of measurement. If the force is expressed in pounds, the weight must also be expressed in pounds. If the force is expressed in grams, in what unit must the weight be expressed? Both distances must be expressed in the same unit. If one distance is expressed in feet and the other in inches, what must be done before using the formula?

Special problem. If a force of 50 pounds moves 15 feet in raising a weight of 250 pounds, how far has the weight been moved?

If a force of 25 pounds is to be used to raise a weight of 100 pounds, through what distance must it move to raise the weight 3 feet?

What are the classes of levers? By examining the drawings in Figure 187 we observe that the force, the fulcrum, and the weight are not always in the same positions with respect to one another. Scissors, weighing balances, and most pump handles have the fulcrum between the point where the force is applied and the point where the weight is to be lifted or the resistance is to be overcome; they are *levers of the first class.* The nutcracker, the ordinary can-opener, and the wheelbarrow have the weight or resistance between the force applied and the fulcrum; they are *levers of the second class.* Grass shears and sugar tongs, in which the force applied is between the weight and the fulcrum, are *levers of the third class.*

What is meant by mechanical advantage? You know that a machine is a device to aid man in doing certain work advantageously and efficiently. We use levers of the first and second classes because they enable us to lift heavy weights by the application of much less force than would otherwise be needed. In levers of the first and second classes the weight lifted is always greater than the force applied. In a lever of the third class, however, the force applied is greater than the weight lifted or the resistance overcome. We use a lever of the third class in order to move a weight through a greater distance than the force moves (Fig. 188). Since the weight moves through a greater distance than does the force, it must move more rapidly.

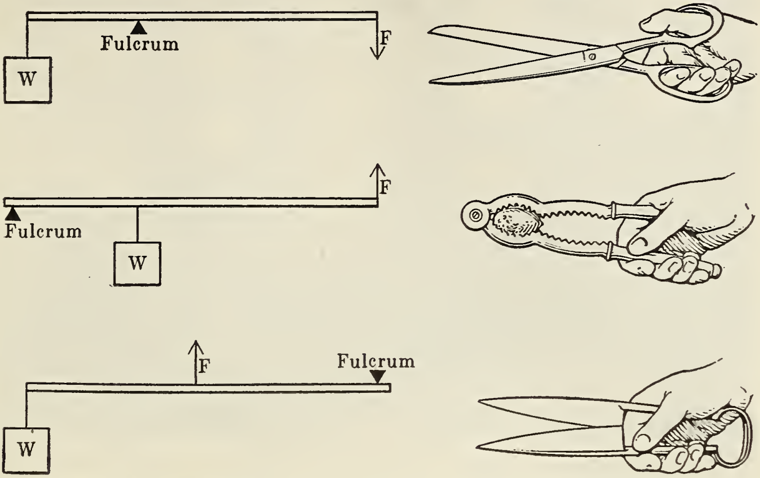


FIG. 187. The drawing at the top shows a lever of the first class; the middle one, a lever of the second class; the bottom one, a lever of the third class. Find in the drawing at the right an illustration of each kind of lever.

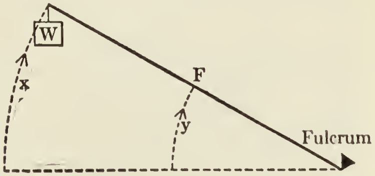


FIG. 188. With this lever is the force, *F*, applied, greater or less than the weight, *W*, lifted? Is the distance, *Y*, through which the force acts, greater or less than the distance, *X*, through which the weight moves? What are the advantages of such a lever?

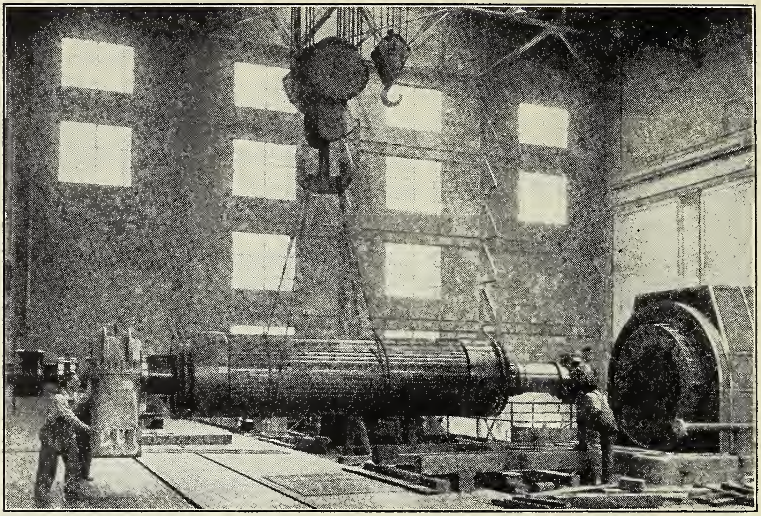


FIG. 189. A system of pulleys used to assemble an electric generator driven by a steam turbine such as the one shown in Fig. 179.

Close observation reveals the fact that all machinery is made (1) for the purpose of overcoming greater resistance than the force applied; or (2) for the purpose of moving the weight or performing the operation at a greater speed than that of the force applied; or (3) for changing the direction or application of the force. For example, a passenger train locomotive is designed for speed; consequently the driving wheels are made large so that they cover a greater distance in one revolution than the smaller driving wheels of a freight train locomotive of the same power, which is designed to pull heavier loads.

Special problem. Explain how the principle of sacrificing speed for force, or force for speed, is applied to the three transmission gears of an automobile.

The ability of a machine to move a weight or to overcome a resistance, as compared with the amount of force applied, is referred to as its *mechanical advantage.* If the force acting on a lever is five feet from the fulcrum and the weight is one foot from it, a force of one pound can raise a weight of five pounds. The ratio of the weight to the force is 5 to 1 or 5, and we therefore say that this lever has a mechanical advantage of 5. A machine cannot do any work by itself; if work is done on it, then it in turn does work. In other words, a machine can only transmit the force or work applied to it according to its mechanical advantage.

Rope and pulleys. The use of ropes and pulleys for lifting weights is familiar to most of you (Fig. 189).

Figure 190 is a drawing of a single fixed *pulley*. In this pulley the only advantages gained are the height to which a weight can be raised and the position which can be assumed by the person operating the pulley. For example, by this pulley a man can lift a hundred-pound sack of sugar to a storage bin several feet in the air while he stands on the floor. The force applied to lift the sack of sugar, however, is one hundred pounds, that is, a force equal to the weight of the sack of sugar.

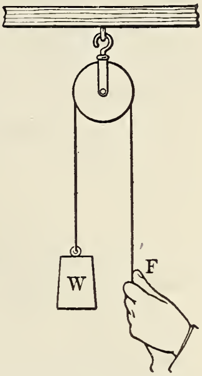


Fig. 190. How does the force applied to this single fixed pulley compare with the weight?

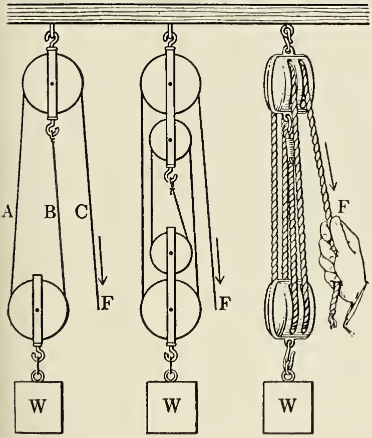


Fig. 191. Disregarding friction and the weight of the movable pulley, what weight can be raised by a force of 500 grams with the system of pulleys at the left? In the middle? The system of pulleys at the right is called a block and tackle.

With the single fixed pulley there are two strands of rope: the one which supports the weight, called the supporting strand; and the one to which the force is applied. The strand in a single fixed pulley to which the force is applied is subjected to the same strain as the strand which supports the weight. As the ratio of the weight lifted to the force applied is one, the mechanical advantage of this pulley is one.

Figure 191 shows at the left a system of pulleys in which the weight is supported by two strands. Suppose the weight to be lifted is 200 pounds. If we disregard the weight of the movable pulley, tell how many pounds are being supported by rope A; by rope B. Rope A is connected directly with rope C over a single pulley. Therefore, how many pounds of force are exerted on rope C? Note that the force is equal to the weight divided by the number of the supporting strands.

If W represents the weight, F the force, and n the number of supporting strands:

$$\mathrm{W = Fn.}$$

Notice that the law of machines holds true for the pulley. To move the weight of 200 pounds up 1 foot, the force of 100 pounds must move 2 feet.

Experiment 79. To show how pulleys aid in doing work. Suspend two double block pulleys as shown in the central diagram of Figure 191 or as shown in the right-hand diagram. In either case, how many strands support the weight?

Attach a small bag or box to the strand where the force is applied and fill it with shot or small weights until the force will just balance the four supporting strands and the movable block. Why is this done? To the lower block attach 200 grams as the weight to be lifted. Use the formula $W = Fn$ to calculate the number of grams needed to balance the weight of 200 grams. Add this number of grams to the weights in the box attached to the force strand. Does this force raise the weight after you have overcome inertia? Was your calculation correct? Do the weights raise 200 grams? With your hand, raise the 200 grams 3 inches. Through how many inches did the force move as this was done? Does the law of machines hold true in this case?

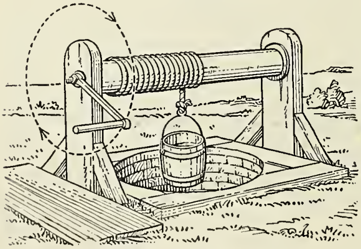


FIG. 192. A windlass used to draw water from a well is an illustration of what kind of machine?

Wheel and axle. Figure 192 shows a simple machine used from early times to draw water from a well. It is called a *wheel and axle.* Notice that a force applied to the handle moves in a circle (wheel). As the force moves once along the circumference of the wheel, the weight is raised a distance equal to the circumference of the axle. Which is longer, the circumference of the wheel or the circumference of the axle? Will a force applied to the wheel need to be smaller or larger than the weight to be raised?

Figure 193 shows a diagram of a simple form of the wheel and axle. If the radius *OA* of the wheel is 12 inches, the force will travel $2 \times \pi \times 12$, that is 75.36 inches in each revolution. If the radius *OC* of the axle is 3 inches, the weight will travel $2 \times \pi \times 3$, that is 18.84 inches, during the same time. If a force of 5 pounds is applied, we can find the weight lifted thus:

$$5 \times 75.36 = W \times 18.84$$

$$W = \frac{376.80}{18.84} = 20 \text{ lb.}$$

Stated in terms of the law of machines, the force times the distance through which the force moves equals the weight times the distance through which the weight moves.

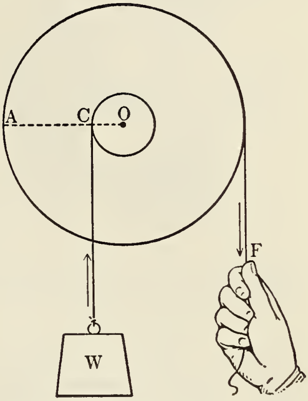


FIG. 193. Principle of the wheel and axle. *OC* corresponds to what in Fig. 192? *OA* corresponds to what?

Although the circumferences of the wheel and axle represent the actual distances through which the force and weight move, we may make our work easier by using a property of all circles, namely that the circumference is always found by multiplying the radius by 2 and by 3.1416.

If we were to indicate each circumference in the example above, notice what would happen:

$$W = \frac{5 \times \cancel{2} \times \cancel{3.1416} \times 12}{\cancel{2} \times \cancel{3.1416} \times 3} = \frac{5 \times 12}{3} = 20 \text{ lb.}$$

Because of the way in which the factors cancel, we can use the radii of the wheel and the axle in place of the circumferences and still get the same result.

Special problem. The radius of a wheel is 2 feet and the radius of its axle is 4 inches. What force must be applied to the wheel to raise a weight of 600 pounds on the axle?

In the windlass, which is a form of the wheel and axle, a crank takes the place of the wheel; the crank moves in a circle, the rim of a wheel. Figure 194 shows how two machines of the wheel and axle type may be combined to lift enormous weights. By using the small cogwheel which drives the larger one, a great deal of speed is lost; but there is a corresponding gain in power which enables us to lift greater weights. Many useful devices operate in the form of the wheel and axle, such as the crank of an automobile, a coffee grinder, a grindstone, an egg-beater, and a capstan. What other applications of the wheel and axle can you add to this list?

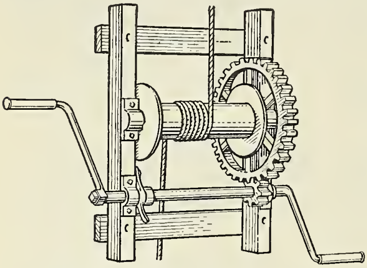


FIG. 194. This machine is a combination of what two machines of the same kind?

How is the inclined plane used to do work? You have all observed one or more of the following examples of the inclined plane: planks used to load a piano on to a truck, an escalator, a winding mountain road, or a plank extending from the ground to the floor of a freight car. Think of several other examples of the inclined plane.

Experiment 80. To show how an inclined plane aids in doing work. Arrange a board against a table (Fig. 195) so that it makes an angle of approximately 30° with the table. Attach a cord to a small wagon or to a roller skate as shown in the illustration. Weigh the wagon. By adding weights to the cord, find the force needed to cause the wagon to move up the incline slowly. What is the force (weight) needed? Remove weights until the wagon moves very slowly down the incline. What is the force needed?

The average of these two forces may be considered the force which would cause the wagon to move up the plane if there were no friction. Why? The force acts through the distance the wagon moves. But what is the actual distance the weight is raised vertically from the floor to the table? The height of the plane (*B* to *C*) is the distance the weight is raised, and the length of the plane is the distance through which the force acts.

In the inclined plane $FD = WD'$. Tell what each letter represents in Figure 195.

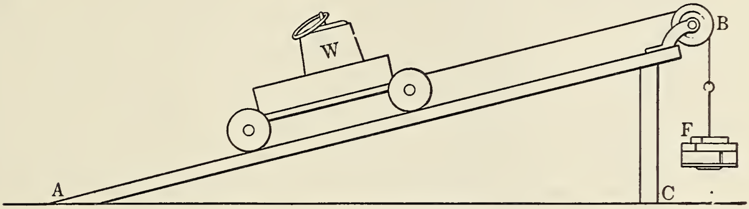


Fig. 195. If this inclined plane is 14 in. long and its height *B* is 2 in., what force will be needed to pull a weight of 21 oz. the length of the plane?

Special problem. How long must an inclined plane be so that a force of 100 pounds will roll a barrel weighing 400 pounds to the floor of a truck 4 feet above the ground? Use the formula $FD = WD'$.

How is the screw used to do work? The screw and the wedge are forms of the inclined plane much used in modern machinery.

Experiment 81. To show the principle of the screw. Cut a piece of paper so as to form a right-angled triangle (Fig. 196). The side *AB* represents an inclined plane. Wind the paper around a pencil. Notice that the edge of the paper has the form of a screw. With your finger trace the inclined plane (screw) from the bottom to the top of the pencil.

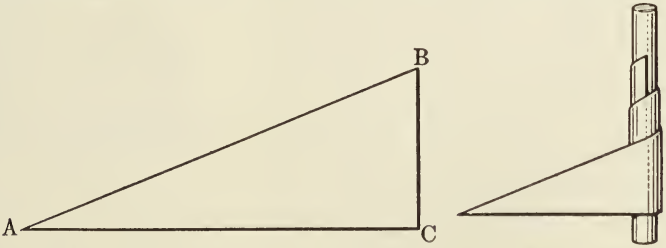


Fig. 196. The screw is a form of the inclined plane. Explain.

The ridge running spirally around the screw is the *thread;* the distance between two consecutive turns of the thread is the *pitch* of the screw. The ratio of the circumference of the screw to the pitch is the mechanical advantage of the screw?

The jackscrew (Fig. 197), used frequently in raising buildings, is a very powerful device, because the force moves through a long distance while the weight moves through a very short distance. Suppose the handle of the jackscrew to be 4 feet long and the pitch of the screw $\frac{1}{2}$ inch. Then, as the handle moves in a circle about 25 feet ($4 \times 2 \times 3.14$) in circumference, the screw is moved up $\frac{1}{2}$ inch. If we disregard friction, a force of 1 pound exerted at the end of the handle will lift 600 pounds, since $\frac{1}{2}$ inch is contained in 25 feet 600 times.

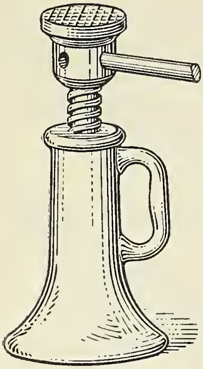


FIG. 197. Why is a jackscrew a powerful enough device to raise heavy weights?

Among the many examples of the screw as a machine are various kinds of clamps used in wood working, vises, meat grinders, fruit presses and water faucets. What others can you name?

Special problem. What weight will the jackscrew in Figure 197 lift if the force applied is 10 pounds? Use the formula $FD = WD'$.

Why are screws used in furniture? Is it easier to pull a screw out of a board than a nail? Why? Would a screw pull loose as easily as a nail? Why are screws used to hold furniture together?

The wedge. Another form of the inclined plane is the familiar machine called the *wedge*. It is used principally for splitting materials or for forcing them apart. Figure 198 illustrates the use of the wedge in splitting wood. Probably the first wedge was an axe made by primitive man during the Stone Age. The axe has been a useful tool ever since. We do not always think of a cutting edge as a wedge, but it is; and every time you use a knife you use a wedge.

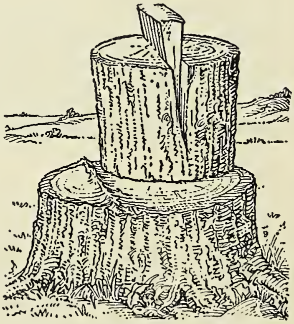


FIG. 198. Force applied to this wedge by a blow from a mallet or a sledge hammer splits the wood. Name several examples of the wedge.

PROBLEM: HOW IS THE EFFICIENCY OF A MACHINE MEASURED, AND HOW IS ITS POWER TRANSMITTED?

Efficiency of machines. Many experiments have shown that not all the force applied to a machine is used by the machine to do useful work. Some force is required to overcome the inertia of the movable parts of the machine and to overcome the friction caused by the sliding of a moving part over a fixed part or of two moving parts on each other. So the law of machines is actually true only when we suppose that friction and inertia do not exist. But since friction is present and inertia has to be overcome in all moving parts of machinery, no machine has ever been made that does as much work as is done upon it. In other words, no known machine is one hundred per cent efficient.

If three-fourths of the work done on a machine is available for useful work, while one-fourth is used in overcoming friction in the machine and in overcoming the inertia of its parts, we say the efficiency of the machine is three-fourths, that is, 75%.

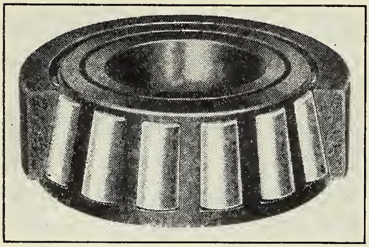
$$\text{Efficiency} = \frac{\text{Work done by the machine}}{\text{Work done upon the machine}}$$

Why does decreasing friction in a machine increase its efficiency?

How is friction lessened? Rub two boards together. Note that the effort required is due largely to friction. Notice also that heat is generated. Place two round pencils between the boards and rub the boards together again. Do the boards move more easily? Do rollers decrease the friction between the boards?

If heavy grease is placed between two boards, they will move over each other much more freely than when they are dry. Suggest a reason. Soap placed between them will produce a similar effect.

If castors are placed under a piece of heavy furniture, it can be moved more easily because the friction between the rolling castors and the floor is less than the friction caused by sliding the piece of furniture. In modern machinery a large number and variety of roller bearings are used to reduce to a minimum the loss of efficiency due to friction. You have probably noticed the ball bearings of a bicycle or the roller bearings in the front wheel of an automobile (Fig. 199).



Courtesy Timken Roller Bearing Co.

FIG. 199. A tapered roller bearing. Why are bearings used?

Lubrication. The place where the hub of a revolving wheel slides on a shaft is called a bearing. Whether a wheel is equipped with ball, roller, or sliding bearings, these bearings must be oiled or greased, *lubricated*, to reduce friction as much as possible and thereby prevent the generation of heat that would tend to destroy the bearings.

Experiment 82. To show why lubricants are needed on bearings. Look through a magnifying glass at a cylindrical piece of metal that appears smooth to the unaided eye. Do you see a smooth surface? Observe carefully the scratches and holes in the supposedly smooth surface. Would greasing the surface make it smoother? Why?

The bearings of a machine may appear to be perfectly smooth, but a careful examination through a magnifying glass will reveal rough places. These rough places on an axle, or on the bearing supporting it, would cause friction which would in time produce enough heat to burn out and destroy both axle and bearing. To prevent as much friction as possible, *lubricants*, that is, oil and grease, are used. When a lubricant is placed on a bearing, it fills the tiny scratches and holes so that the shaft really turns on a film of oil or grease. As a result, the metal bearing and the shaft are prevented from sliding on each other; i.e., friction is lessened and but little heat is generated.

Unless dirt, especially sand, is kept out of bearings, the resulting friction will generate so much heat that the bearings will be seriously damaged. The molecules of lubricating oil and grease should have a low degree of cohesion so that they will spread readily over surfaces. On the other hand, the oil or grease must not

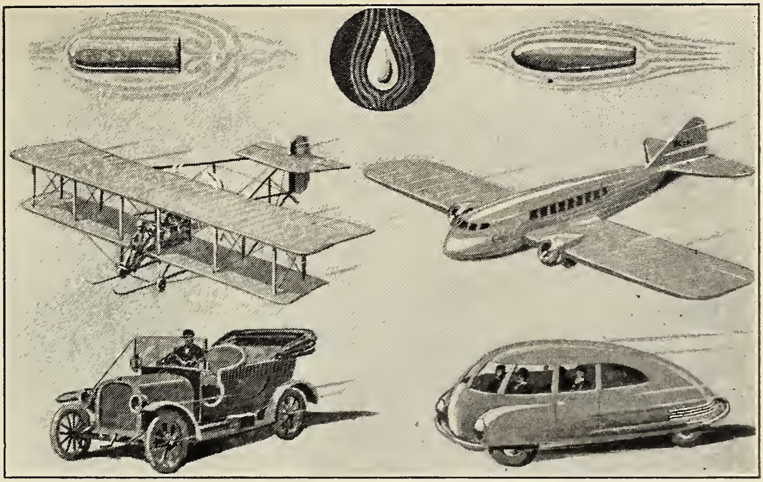


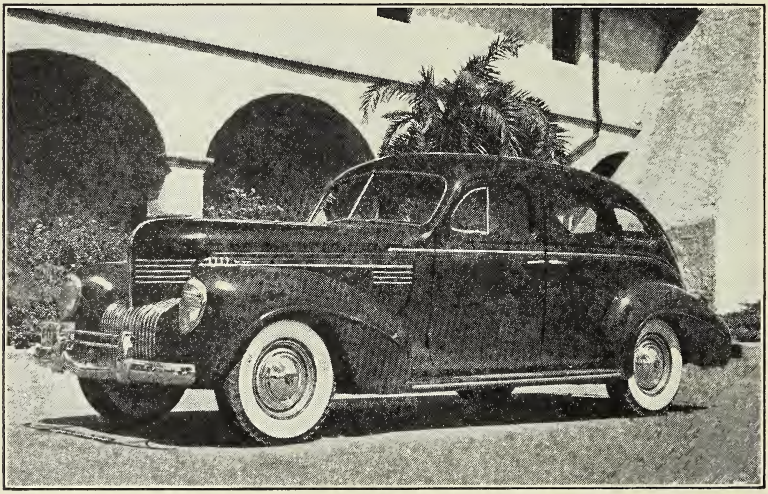
Fig. 200. Compare the shape of the falling drop of water at the upper center and the car at the right. Which of the above objects are streamlined?

be so thin that the pressure in the bearings forces it away from the place where moving parts cause friction. The lubricant must be free from any substance that would corrode the bearings, or that would absorb oxygen and thus cause the mixture to become thick and gummy. Vegetable oils, such as castor oil, become gummy; animal oils and fats tend to decompose and thereby to form corrosive acids. Mineral oils from crude petroleum are the best lubricants for most machines. By new methods of refining petroleum, lubricating oils for all purposes and conditions are being refined. Summer and winter oils for automobiles are good examples.

Streamlining. When the first cars, trains, and airplanes were designed, great attention was given to reducing resistance of bearings. Why? Not until cars, trains, and airplanes were driven at high speeds was an effort made to reduce air resistance.

It has been found that resistance caused by friction of bearings increases in direct proportion to the speed. Air resistance increases as the square of the speed; that is, if the speed is doubled, the air resistance is increased four times. The power necessary to overcome air resistance increases as the cube of speed. Therefore, doubling the speed requires that the power to overcome air resistance be increased eight times.

A drop of water falling through the air assumes the shape shown in Fig. 200. A drop this shape meets with the minimum resistance of air as it falls. It is "streamlined."



Courtesy Chrysler Corporation

FIG. 201. Is this car streamlined? Compare its shape with the streamlined car in Fig. 200.

In front of an object which is passing through air at a high rate of speed and which is shaped like the bullet on the left (Fig. 200), air pressure is increased; behind it air pressure is decreased. This difference in pressure tends to slow up the bullet. Explain why.

In front and behind a streamlined object like the bullet on the right (Fig. 200) air pressure is changed little; consequently, little resistance is offered to it by the air. Why?

Most boats, airplanes, racing cars, and trains which are being built today are streamlined. Each year advances are made in the streamlining of automobiles.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

bearing
capstan
efficiency
foot-pound
formula
friction
fulcrum
gears
gram-centimeter
horse power
inclined plane
lever
lubricants
machine
manufacture
mechanical advantage
pitch
pulley
resistance
screw
specialize
strand
tool
transmitted
wedge
wheel and axle
work

Write the number of each item on your paper, and after it the word that completes the statement.

1. The unit for measuring work in the English system is __________.
2. The unit for measuring work in the metric system is __________.
3. Power is the __________ of doing work.
4. There are __________ simple machines.
5. A wheel barrow is an example of a lever of the __________ class.
6. Sugar tongs use the principle of a lever of the __________ class.
7. A machine is a device to aid man in doing __________.
8. Bearings of a machine become hot because of __________.
9. The unit used to measure power is the __________.
10. The point around which a lever rotates is called the __________.
11. The purpose of lubrication is to lessen __________.
12. Belts are used for the purpose of __________ power.

13. The ratio of the resistance overcome, to the force applied to a machine is called the: efficiency; power; useful work; energy; mechanical advantage of the machine.

14. The ratio of the useful work done by a machine to the total work expended upon it is referred to as the: efficiency; mechanical advantage; friction; power transmission; general law of the machine.

Which of these statements are true? If any are false, re-state them in correct form.

15. In a scientific sense the only work performed in solving a problem in algebra is in moving the pencil.
16. A nut cracker is an example of a wedge.
17. A vacuum cleaner is a simple machine.
18. Vegetable oils make better lubricants than petroleum oils.
19. A spiral staircase is an example of a wheel and axle.
20. The steam engine is a very efficient machine.

THOUGHT EXERCISES FOR UNIT IX

Principles of Science

State the principles of science in this unit in the form of sentences. One of them is: A force multiplied by the distance through which it acts is equal to the weight multiplied by the distance through which it is moved.

Questions or Problems

1. Are there as many persons working to supply your needs and pleasures as there were for a king in the seventeenth century? Discuss your answer.
2. Suppose a man shovels a ton of coal in less time than a small boy. Do they each do the same amount of work? How does the work of the man indicate that he exerts more power than the boy?
3. How much work do you perform in walking up the stairs in your home?
4. If an automobile engine is doing 16,500 ft.-lb. of work per second, what is the horse power of the engine?
5. What kind of machine may movers use to load a piano upon a "moving" van?
6. Why do you suppose the Bronze Age of man preceded the Iron Age?
7. Where is the fulcrum on a wheelbarrow?
8. Engineers consider the principle of one of the simple machines in locating a road over a mountain. Which one?
9. Why is a jack screw such a powerful device?
10. What kind of a machine is a capstan? A windlass? A bicycle pedal?

11. The radius of a wheel is two feet, and that of the axle, four inches. What force will be required to raise a weight of 600 pounds?

12. What advantage does a person gain in using a lever of the third class?

13. If a fulcrum is placed one foot from one end of a six foot rod, how much force would be required on the other end to raise a weight of 500 pounds?

14. Name five uses of friction in our everyday life.

15. How many supporting strands of a system of rope and pulleys would be required to raise a thousand pounds with a force of 250 pounds?

16. What would be the efficiency of a machine that requires 2500 ft.-lb. of work applied to it to receive 1625 ft.-lb. of useful work?

17. How does the word "power" differ in meaning from the word "force"?

Projects and Reports

1. Study a complicated machine like a steam shovel, harvesting machine, or automobile. Make sketches of parts and label each which represent the simple machines.

2. Make a study in factories and books of the different kinds of cog wheels. Draw sketches and label the kinds of gears.

3. Make a careful survey of your home to find out examples of the simple machines which operate there. Read your list to the class.

4. Study in science books and encyclopedias the origin of the term "horse power" and report to the class.

5. Study the history of the simple machines and explain how they have affected man's mode of living.

References for Reading and Study

1. Clarke and Small, *The Boys' Book of Physics,* Chapter V. E. P. Dutton and Company.

2. Decker, W. F., *Story of the Engine.* Charles Scribner's Sons.

3. Hathaway, Esse V., *Partners in Progress.* McGraw-Hill Book Company.

4. Lynde, C. J., *Everyday Physics,* Chapters I and II. The Macmillan Company.

5. Ogburn, Wm. F., *You and Machines.* National Capitol Press, Inc., Washington, D. C.

UNIT X

HOW DOES MAN SECURE HEAT FOR HIS DAILY NEEDS?

Exploring the Production and Use of Heat

Probably man lived on the Earth for long periods of time without fire. Because of this, his food was eaten raw, and he was without means to protect himself from the cold. We can only imagine that man must have known about fire long before he knew how to make use of it. He may have learned of its warming effects by coming close to a burning tree that had been set on fire by lightning. He probably noticed too that wild animals kept outside the circle of light of a burning tree. To this fire, he may have learned how to add wood to keep it burning so that he could cook food, warm himself, and protect himself from wild animals. Later we know that he carried fire from one place to another. Even as late as ancient Greece, a fire was carefully guarded in each city because fire was essential to the welfare and happiness of the people. So essential is fire to our welfare and happiness that our modern civilization is said to have been ushered in as man learned how to use and control fire.

Ever since man has learned how to make and control fire, he has been studying the effects of heat on different substances. He must know the effects of heat upon iron when he builds a bridge or a railroad. Because he has learned that liquids and gases expand when heated, he has constructed instruments for measuring temperature. Many of the devices used to control fire in the production of heat depend upon the effects of heat upon metals.

Early scientists believed that heat was a kind of fluid that flowed from a heated body to a colder one. They became puzzled, however, when they considered the great space between the Earth and the Sun, the source of nearly all the heat on the earth. How could a fluid travel through that space? Later they learned as we know today that heat is a form of energy and that all heated objects are sending off heat energy into space. A study of this chapter will show how our comfort and happiness depend upon the control and use of fire in the production of heat.

CHAPTER XIX

FROM WHAT SOURCES DOES MAN SECURE HEAT?

Do you know:

That when you burn coal you are releasing some of the heat that came from the sun millions of years ago? Why kindling wood is used to start a coal fire? Why charcoal is used to purify the air in a refrigerator? How soft and hard coal differ? That delicate perfumes are made from coal? How gasoline is produced?

What actually happens when wood burns? What causes smoke? How matches are made? Four ways of producing heat other than burning a fuel?

PROBLEM: WHY DO WE NEED HEAT IN OUR HOMES?

What is the earth's greatest source of heat? As you already know, the earth's greatest source of heat is the sun. At or near sea level in the tropics the earth receives so much direct heat from the sun that the weather is hot all of the year. In the temperate regions the earth also receives much heat from the sun, although less than in the tropics, and as one goes still farther toward the poles, the amount of heat received by the earth is less and less.

The direct heat from the sun not only helps to keep people warm, but it also makes possible the growth of plants, which store up energy from the sun. The energy stored in certain of these plants furnishes man with heat. Thus, our heat is received indirectly, as well as directly, from the sun.

Although the temperate regions receive vast quantities of heat directly from the sun, it is nevertheless necessary for their inhabitants to use the heat that can be obtained indirectly from the sun to warm their homes during those seasons when the temperature is considerably lower than that in which the human body is comfortable.

Why must we heat our homes? If we are in a room where the temperature is lower than 68° F., we are likely to feel uncomfortable and we may not be able to work efficiently. In most places in the temperate regions the temperature in winter is lower than 68° F. The average annual temperature of the United States is considerably lower than 68° F.; that of New York City from 1873 to 1933 was 52° F. Some of the lowest temperatures recorded by the United States Weather Bureau are 63° F. below zero in Montana, 50° F. below zero on Mt. Washington, and 40° F. below zero on Pike's Peak. While in only a few places in our country are temperatures as low as these reached, it is sufficiently cold in winter in nearly all sections to make it necessary to maintain some sort of heating apparatus.

What are the sources of heat in our homes? We usually maintain the proper temperature in our homes by using the heat produced by a burning fuel. We do make use of the heating effects of electricity; but, while small electric heaters are used in homes, electricity has not yet come into very general use for heating purposes. The heating effects of electricity will be studied in detail in Unit XII.

Problem: What Are the Principal Fuels, and How Does Man Use Them As Sources of Heat?

What is a fuel? In order that a fuel may be practicable for everyday use, it must be a substance that: (1) has a comparatively low kindling temperature; (2) will burn rapidly enough to furnish considerable heat; (3) is able to use oxygen from the air; (4) is available at a reasonable cost; and (5) is safe for general use. The fuels in most general use today are wood, coal, natural and artificial gas, and petroleum products.

How are fuels formed? All fuels, if traced back to their sources, will be found to have come from plant life. The energy of fuels was received from the sun by the growing plant and stored up in its tissues. This energy in fuels is released by burning. When we burn wood, pieces of a plant are used as fuel. In the case of other fuels—gas, coal, and petroleum—the original plant, which stored up energy during its growth many ages ago, has undergone great changes.

Millions of years elapsed while the plants of the Carboniferous Age were being changed to gas, coal, and petroleum. The energy which the growing plant received from the sun and stored in its tissues so long ago was retained, however, and today man is availing himself of this store of energy in coal, gas, and petroleum. In burning these substances, this energy is released to supply man with heat.

A study of history shows that man's advancement in civilization has been largely dependent upon his progress in devising better and better ways of releasing the energy stored in fuels. In the burning of any substance, oxygen is necessary, as you have already learned. One of the great problems, then, which man has been trying to solve is: How can the oxygen which is in air be supplied to burning fuel so as to produce the greatest amount of heat? At first man's methods of securing heat from fuels were very crude. But as he learned more about combustion, he developed better ways of supplying the burning fuels with oxygen, until today houses are heated by furnaces, and our automobiles are run by the heat energy given off by the combustion of gasoline. In industry, too, there are numerous devices for liberating the energy of fuels by combustion.

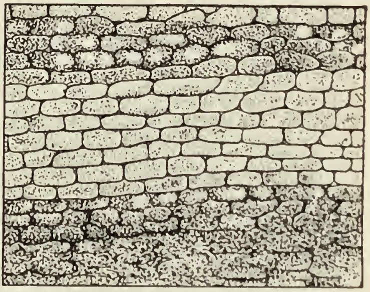


Fig. 202. A specimen of bituminous coal magnified two hundred times. The cell structure proves that this coal began as a plant.

Formation of coal. If we look at a piece of soft coal through a microscope, we find that it is a black mass of vegetable matter (Fig. 202) composed of ferns, leaves, shrubs, and the trunks and roots of trees. Geologists tell us that ages ago, during the Carboniferous Age, ferns and shrubs grew as large as trees do today (Fig. 203). All these enormous plants stored up vast amounts of energy from the sun.

Because of changes in the earth's crust, this luxuriant growth of plant life was covered with water and mud which prevented it from decaying completely; it was sealed up somewhat as a jar of fruit is sealed. Layers of other material accumulated on top of this mass of vegetable matter and compressed it, and in time the layers of compressed vegetable matter became veins of soft (*bituminous*) coal (Fig. 204). In a few sections, especially in eastern Pennsylvania, because of the bending and crumpling of the earth's crust, it is believed igneous material (lava), thrust up to or near a mass of soft coal, baked it into a form of coal called *anthracite*. Since coal was formed during different periods of time and since the earth's crust has been constantly undergoing changes, veins of coal are often separated by layers of limestone and sandstone.

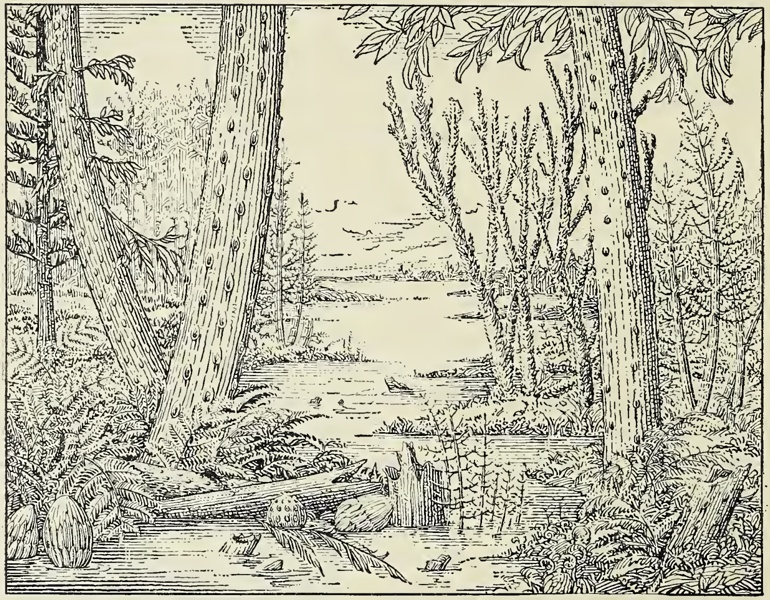


FIG. 203. A landscape of the Carboniferous Age as conceived by scientists and artists. It is believed that most of the vegetation, from which coal was formed, grew during this period.

Formation of natural gas and petroleum. At the same time that coal was being formed, the movements of the earth's crust covered other great masses of plant and animal life (Fig. 205) with water and layers of materials which hardened into limestone

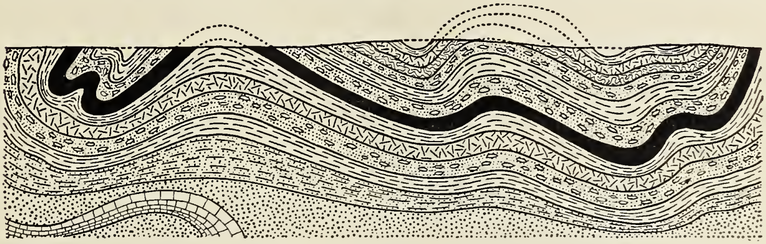


Fig. 204. A vertical section representing layers of the earth's crust. The black strip is a vein of coal. What do the dotted lines represent?

and sandstone. Heat from the interior of the earth and pressure changed these masses of plant life, not into coal, but into natural gas and petroleum (Fig. 206).

The use of wood as fuel. No one knows exactly how prehistoric man discovered fire. It may have been in connection with

American Museum Natural History

Fig. 205. From bones and other evidences scientists believe that many kinds of huge animals, such as the brontosaurus pictured above, lived during the Carboniferous Age.

the eruption of a volcano; or lightning may have struck a dead tree and set it on fire. Can you suggest other ways in which early man may have discovered fire? His fuel was undoubtedly wood, and the same fire furnished heat for cooking and warmth for his body. Dry wood is a good fuel because it has a low kindling temperature; but in many places, especially near cities, wood has now become scarce and therefore expensive; besides there are other fuels that are more easily transported and that furnish heat more continuously. Consequently, in most places in our country, wood is used as a fuel chiefly for kindling coal fires and for burning in fireplaces.

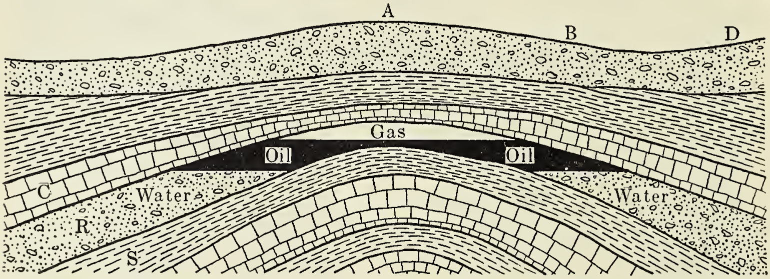


FIG. 206. Conditions under which gas and oil accumulate. *S*, represents the source of gas and oil; *R*, porous rock acting as a reservoir to hold water; *C*, a cover of hard rock which prevents the escape of the gas. What would be obtained if a well were drilled at *A*; at *B*; at *D*?

Experiment 83. To show how wood is made into charcoal. Pour sawdust (very fine wood) into a long, hard glass test tube until the tube is two thirds full. Then heat the tube slowly. Test the gases that are given off by bringing a lighted splinter to the mouth of the test tube. What happens? Notice the tarry liquid deposited on the sides of the test tube. Break the test tube and examine the black porous solid in the bottom of the tube. What is it?

When wood is heated in a closed container and air prevented from entering, several products result: (1) gases, (2) tarry liquids; and (3) a porous black solid called *charcoal*.

How is charcoal manufactured? In a modern charcoal plant (Fig. 207) sticks of wood are loaded upon steel cars, which are run into a long, narrow, iron room called an oven. The room is made air-tight and heated slowly for twenty-four hours. When the cars are drawn out of the oven, the long sticks of wood are found to have been changed into sticks of black charcoal. The gases and tarry liquid which were driven off by the heat have been collected during the process and are condensed into such products as wood alcohol and acetic acid.

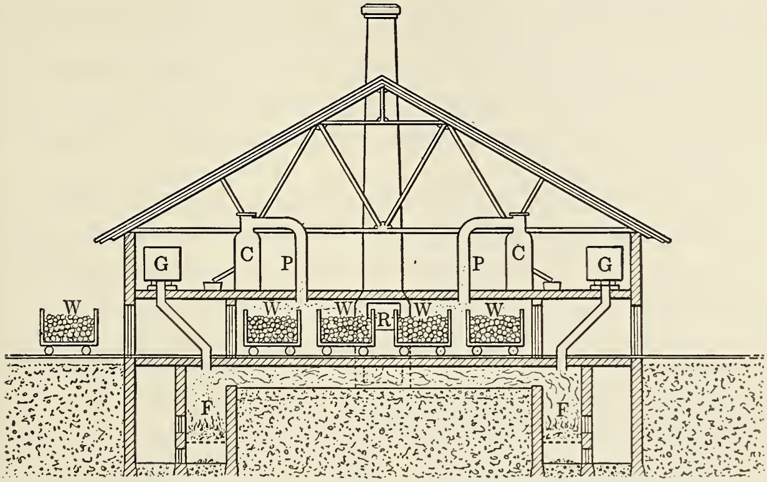


FIG. 207. A charcoal plant. *WW*, represents wood in cars; *PP*, pipes to convey gases; *CC*, gas condensers; *R*, heating room; *GG*, ventilators from which gases are led back to the fires; and *FF*, fires to furnish heat to change wood into charcoal.

The uses of charcoal. Charcoal burns with an intense heat and for this reason is used in melting metals. It is used in making a very fine grade of steel for knife blades, needles, and similar articles. Charcoal is useful in other ways than as a fuel. Since charcoal is not readily affected by moisture and bacteria, fence posts and telegraph poles are sometimes charred before being placed in the ground. Charcoal is very porous, absorbing sixteen hundred times its own volume of certain gases; for this reason it is sometimes used to purify the air in refrigerators, cisterns, and other places in which there may be foul gases. A very fine grade of charcoal is used in gas masks. It is also used in filters, in the manufacture of sugar and certain kinds of gunpowder, and in many other processes in industry.

The uses of coal as a fuel. In the early part of the nineteenth century when railroads were being built throughout the United States, certain people became alarmed at the great amount of wood required for railroad ties and for fuel for locomotives, and protested that the nation's fuel would soon be exhausted. However, it was railroad ties that helped later on to make possible the transportation of vast quantities of other fuels destined to take the place of wood in many homes and in industry. These fuels are coal and oil.

Coal has a higher kindling temperature than wood; that is, coal requires more heat than wood to raise its temperature to the kindling point. Consequently, a wood fire is usually built to kindle a coal fire. A draft, current of air, is also needed to provide a constant supply of oxygen to the burning fuel. Pound for pound, coal gives off more heat than wood; a pound of soft coal gives off about as much heat as two pounds of wood.

Bituminous (soft) coal contains a larger amount of gaseous materials than hard coal does. These materials may pass off as gases. Soft coal burns with a yellow flame and gives off much smoke. In most furnaces the gases from soft coal, instead of burning, pass out of the chimney as part of the smoke. As smoke is injurious to health and as it discolors houses and furnishings, the use of soft coal in residential districts is undesirable.

Anthracite (hard coal) contains a larger amount of carbon available for combustion than bituminous coal; certain kinds contain as much as 81 per cent of carbon. Anthracite burns with a blue flame and gives off very little smoke. For this reason it is more desirable for use in residential districts.

Experiment 84. To show how coal is changed into coke. Place a small quantity of powdered bituminous coal in a test tube. Heat the tube gently and at the same time hold a lighted splint over its mouth. What happens? Heat the test tube strongly for a few minutes longer. Observe the dry, porous solid at the bottom of the tube. On the sides of the tube near the top do you see drops of liquid and a black sticky substance that looks like tar?

The dry, porous solid at the bottom of the tube is *coke*. The gas which burned at the mouth of the test tube is *coal gas*, which in many places is used for heating and lighting. The black sticky substance which clings to the side of the test tube is *coal tar.* For many years the coal tar obtained in the process of making coke was not used. Indeed, half of the coke ovens in operation today do not make use of it, even though it is a very valuable and useful substance. From coal tar are manufactured dyestuffs, explosives, carbolic acid, aspirin, indigo, perfumes, paints, paving materials, roofing, insulating material, and the like.

Many of the drops of the liquid on the inside of the test tube are probably drops of ammonia liquor, from which a number of useful products is manufactured; the most valuable of which is ammonium sulfate, used widely in industry.

The following table gives an idea of some of the different substances that may be obtained from one ton of bituminous coal in the process of making coke.

Coal 1 ton (2000 lb.)	Ammonia liquor 20 gallons	Ammonium chloride (batteries, soldering, etc.) Ammonium nitrate (explosives) Ammonium sulfate (fertilizer) Ammonia for refrigeration	
	Gas 10,000 to 12,000 cubic feet	Benzene—motor fuel Fuel for heating Gas for illumination	
	Coke 1200 to 1500 pounds	Fuel, used principally in the manufacture of steel Carbon from which electrodes are made Black paint Graphite	
	Tar 120 pounds	Pitch Asphalt Insulators Artificial silk Aniline dyes Perfumes Baking soda	Saccharine Aspirin Soap Photo developer Carbolic acid T. N. T. Picric acid

How is coke manufactured commercially? Coke is manufactured by heating slowly suitable grades of soft coal in air-tight ovens (iron retorts). Soon after the heating process commences, the coal begins to decompose and settle down in the retort. As the coal is more highly heated, it becomes soft and gives off coal gas, which is conveyed into large storage tanks. As the heating continues, coal tar products are driven off. These are made into a variety of useful substances. After the gases and tarry liquids have been driven off, the carbon remaining finally becomes hard and brittle; in this state it is called *coke.* While the coke is still hot, it is pushed from the ovens, drenched with water to cool it, and then stored for use. The chief use of coke is in the manufacture of steel. In communities where the chief reason for converting coal into coke is to obtain coal gas, the coke is considered the by-product and is sold for use as fuel.

The use of gas as a fuel. Gas is an excellent fuel, especially for cooking, since it produces a flame instantly. Furthermore, a gas flame can be extinguished immediately when heat is no longer desired, whereas a wood or coal fire keeps on burning after heat is no longer needed. Natural gas is so much in demand for heating and lighting purposes that it is pumped hundreds of miles from natural reservoirs in the earth (Fig. 206) to places in which it is to be used. It consists largely of hydrogen and *marsh gas.* Marsh gas is a colorless, combustible gas, so called because it forms naturally in swampy or marshy places. Natural gas burns with a pale, blue flame producing an intense heat when the burner is properly adjusted. It is composed of hydrogen and carbon and is therefore called a *hydrocarbon.*

In many places where natural gas is not available, artificial (coal) gas is used for fuel.

What is petroleum? *Petroleum* is a dark, oily liquid composed of hydrocarbons. It is obtained from oil wells in Texas, California, Oklahoma, Wyoming, Pennsylvania, and many other states. Outside of our country it is found extensively in Russia, Persia, Rumania, Mexico, Venezuela, Colombia, the Dutch East Indies and other places. Petroleum has been known for centuries, although very little use has been made of it until recent years.

As early as the thirteenth century Marco Polo reports that on his journey through Armenia and Persia he noticed large supplies of a "liquor-like oil which is good for burning." This undoubtedly was petroleum. Ancient peoples who lived in the Tigris-Euphrates Valley used it to make boats water-tight; it is still used there for this purpose.

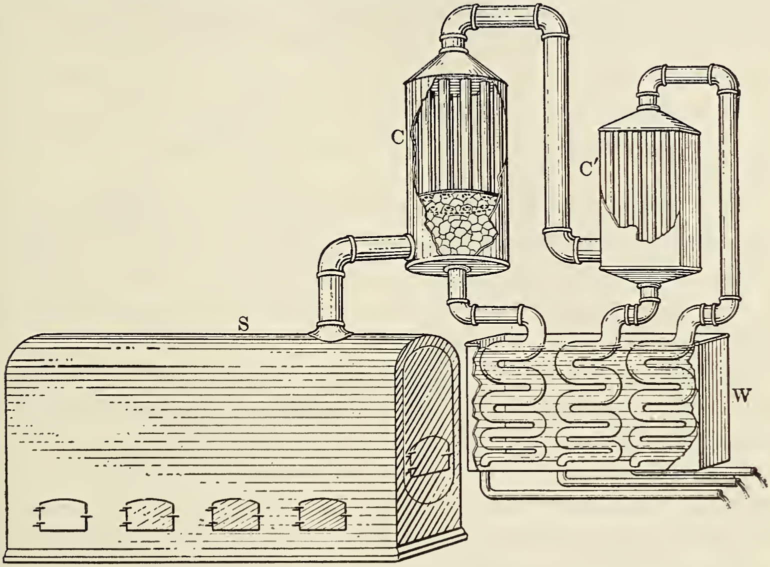


FIG. 208. Apparatus for the distillation of petroleum. *S*, still; *C* and *C′*, air cooled condensers; *W*, water tank through which pipes from *C* and *C′* are run to complete the condensation.

What are the uses of some of the substances obtained from petroleum? Petroleum is a mixture of many compounds, from which a variety of useful materials is obtained. The crude petroleum taken from wells bored through rock by drilling is refined by distillation in large iron stills (air-tight ovens) (Fig. 208). Some of the products of distillation pass off as vapor at a rather low temperature. Those vaporizing between approximately 70° and 150° C., that is, having a boiling point between 70° and 150° C., are known as *naphthas*. One of the naphthas having a low boiling point is *gasoline*, used for fuel in stoves and motors.

Benzine, another naphtha with a low boiling point, is used for dry cleaning and for other cleaning purposes. Naphthas with higher boiling points are used in making paints.

When in the process of distillation the temperature of the petroleum is increased from 150° to 300° C., kerosene and the fuel oils used in stoves, furnaces, and boilers are driven off in gaseous form. Kerosene is still in demand for kerosene lamps where gas or electricity is not available. It is also used as fuel for certain kinds of gas engines, such as those used in tractors (see Fig. 142, page 232).

As the temperature of the petroleum is raised still higher, other substances, such as vaseline and paraffin, are driven off in gaseous form. From the remaining petroleum products, heavy greases, salves, lamp black, and the substance used as the base of chewing gum are made.

Oil burners are used to furnish power in many ocean liners and in locomotives, and for heat for dwellings, office buildings, and the like. For heating homes oil obtained from petroleum has a number of advantages over coal and wood. If an oil burner is properly regulated, the oil will burn completely; hence it is a clean fuel. An oil burner is regulated automatically and thus the work required in renewing a coal fire is unnecessary. Each kind of oil burner uses a certain grade of oil better than any other.

Problem: How Is a Flame Produced, and What Are Some of the Products of Combustion?

What causes a flame? Such fuels as coke and charcoal glow when burning, but most fuels, such as wood, coal, oils, and gases, burn with a flame. Let us investigate the burning of a few substances to determine what causes a flame.

Experiment 85. To show what causes a flame when wood burns. Hold a splint of wood in a Bunsen flame until it is ignited. Extinguish the flame of the burning splint and notice that the glowing splint gives off smoke. Now quickly bring the smoking splint near the Bunsen flame. Notice the flash of the burning smoke that re-lights the splints. What do you think caused the flash? From this experiment, what do you conclude causes the flame when wood burns?

Experiment 86. To show that a flame is produced by a burning gas. Put one end of a short glass tube in the center of a Bunsen flame (Fig. 209). Hold a lighted splint to the other end of the tube. What happens?

Heat a short glass tube and hold one end in the flame of a burning candle in the cone nearest the wick. Hold a burning splint to the other end of the tube. What happens? What do you think caused the flame?

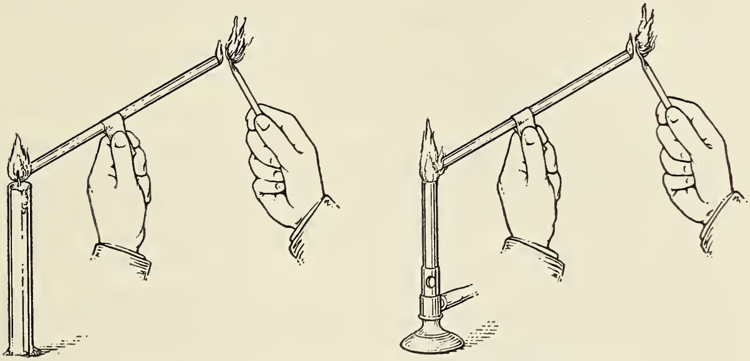


Fig. 209. What is passing through the glass tube?

These experiments teach us that a flame is produced only when gases burn. A burning candle is a tiny gas plant. The material of which the candle is composed is changed by heat, first into a liquid, and then into a gas. The burning gas produces the flame.

How are carbon dioxide and carbon monoxide formed? The carbon in a burning fuel unites with oxygen, which may be either present in the fuel itself or supplied by the air. If there is sufficient oxygen present when a fuel burns, one atom of carbon will unite with two atoms of oxygen to form carbon dioxide. Should there be insufficient oxygen present, one atom of carbon will unite with only one atom of oxygen, to form a deadly poison, *carbon monoxide.*

Carbon monoxide is an odorless gas. If there is even a very small amount of it in the air which we breathe, it will produce symptoms of poisoning in a very short time because it makes the red corpuscles unable to carry oxygen. Death will occur in a few minutes if we continue to inhale air containing carbon monoxide. Although a person may sometimes be revived after inhaling carbon monoxide, the chemical changes it produces in the body often prove fatal after a little time has elapsed.

Carbon monoxide is frequently produced in gas stoves and gas grates when the supply of oxygen is insufficient. Gas stoves and grates should, therefore, always be connected with a flue through which carbon monoxide may pass off into the outside air. Carbon monoxide also forms in gas engines and automobile engines. For this reason an automobile engine should not be run in a closed garage. As you know, many persons have lost their lives by remaining in a closed garage while an automobile engine was running. There is also a certain amount of danger in the use of coal stoves, for carbon monoxide may be formed there as well. When a fresh supply of coal is put on the fire, care should be taken to provide a sufficient supply of air until the coal has started to burn well. Why?

What is smoke and how can it be prevented? Frequently when a fuel is burning, dense clouds of smoke are produced; this is especially true of soft coal. Smoke is composed of tiny bits of carbon that did not unite with oxygen to form carbon dioxide and of hot gases that were not completely burned. If conditions for burning coal are such that all the gaseous compounds containing carbon are converted into water and carbon dioxide, we say the combustion is perfect. With perfect combustion there is no smoke. To render combustion perfect, the following conditions are necessary: (1) a draft of air sufficient to permit all the carbon to combine with oxygen, forming carbon dioxide; (2) a thorough mixing of air with the gases from the burning fuel; (3) a temperature high enough to cause all of the gases to unite with oxygen to form carbon dioxide and water.

Large quantities of smoke in the atmosphere are injurious to both plant and animal life. If smoke settles on the leaves of plants, it interferes with their respiration. If we breathe it into our lungs and air passages, the delicate linings of these organs are injured. As smoke is carried up into the air by hot gases coming from burning fuels, the particles of carbon in it serve as centers for the condensation of water vapor, thus increasing the number and density of fogs. It is estimated that in London probably twenty per cent of all fogs are caused largely by smoke. The density and duration of fogs caused by other atmospheric conditions are increased by the presence of smoke. The problem of doing away with smoke is an urgent one. In many cities ordinances have been passed which require a more careful firing of furnaces in homes and factories. The enforcement of such ordinances will help to keep our cities reasonably free from smoke.

PROBLEM: ARE THERE OTHER SOURCES OF HEAT BESIDES FUELS?

Heat is also produced by friction. When we rub our hands together briskly, we find that they are warmed. Probably at some time you have noticed smoke or flames coming from one of the axle bearings of a passenger coach or freight car. They were produced by friction; that is, the bearings had become dry from lack of oil or grease, and the resulting friction produced heat sufficient to cause flames and smoke. You have doubtless read how Indians and other primitive peoples produced fire by friction. One way of accomplishing this is by the use of a boring device (Fig. 210).

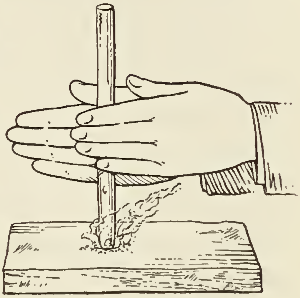


FIG. 210. How can fire be produced by friction?

Special problem. To make fire by friction. If there are Boy Scouts in the class, have them demonstrate a method of starting fire without the aid of a match.

Our ancestors produced fire by friction by striking a piece of flint with steel. When this way of starting a fire was first used, the spark was caused by striking flint with a piece of very hard rock. Later a piece of steel was used instead of rock to produce sparks from the flint, with much better results. The "tinder box" was a metal box containing a piece of flint, a piece of steel, and some burnt cloth called "tinder," which was used to catch the spark and thus start the fire. With the invention of the match, steel and flint were discarded, but it is still friction which produces fire when one strikes a match. A spark produced by the friction of flint and steel is used today in cigarette lighters and in automatic lighters to light a gas stove. If possible, examine one of these lighters and explain how it operates.

How are matches made? The matches made today are the result of many years of experimentation. Wood is cut and split into small sticks. One end of the stick is then soaked in an inflammable material; for example, melted paraffin. Then this end of the stick is dipped into a mixture containing: (1) a compound of phosphorus and sulfur; (2) some substance that will release oxygen easily, as manganese dioxide, red lead, or potassium chlorate; and (3) a sticky substance like glue to bind the materials together. The entire process of making a match, from preparation of the stick to packing in boxes for sale, is by machinery. The drying of matches, after dipping, requires a great deal of care, since handling these inflammable sticks is dangerous work. They will not dry unless the room is dry and hot. On the other hand, if it is too hot they will catch fire; therefore strong currents of air are blown across the matches while they are drying to keep them below the kindling temperature.

How is heat generated by compression? It has been reported that certain of the natives of the Malay Peninsula start fires by the compression of air. They use a wooden tube closed at one end. Some dry bits of leaves are put into the bottom of the tube. A plunger, or piston, is then inserted and forced into the tube with a quick blow of the hand. By compression the air in the tube is heated sufficiently to raise the dry leaves and grass to the kindling temperature. The plunger is pulled out quickly and air is blown into the tube, fanning the dry leaves into a flame.

Experiment 87. To show that heat is generated by compression. Operate vigorously a bicycle or automobile pump that is well oiled and in good working condition. Now work the pump while holding your finger over the air tube leading from the pump. Explain the cause of the increased temperature of the air in the cylinder of the pump.

While the increased temperature of the air in the cylinder was caused to a certain extent by friction of the piston against the walls of the cylinder, it was due chiefly to the heat produced by forcing the molecules of the gases of the air closer together, thereby changing the kinetic energy of their molecules into heat energy. Experiments prove that the temperature of a gas will rise from 0° C. to 87° C. when the gas is suddenly compressed to one-half its original volume. Heat produced in gasoline motors is to some extent the result of the compression of gases within the cylinders of the engine.

What are some of the other sources of heat? In a boring in the earth more than a mile deep at Schladebach, Germany, the temperature increased one degree Fahrenheit for every sixty-seven feet of depth. If the temperature continues to increase at this rate, it would mean that at a depth of thirty-five miles in the interior of the earth the temperature would be about 3000° F. The increase in temperature in this boring in Germany, the fact that the temperatures are higher at the bottom of deep mines than at the top, and other facts lead scientists to believe that the interior of the earth is highly heated. They are now at work trying to find out more about the heated interior of the earth.

Certain elements, such as radium, are continually giving off heat as they break down into other elements. Some scientists believe that this heat helps to keep the interior of the earth hot.

As you know, a piece of iron placed on an anvil and hammered vigorously gets hot. In fact, when any two objects collide, heat is produced. You have learned that heat is produced when oxidation takes place. The chemical action between many substances produces heat. In Experiment 33 on the preparation of hydrogen, do you remember that the action of the hydrochloric acid on the zinc produced heat? The heat in our bodies needed to sustain life and to furnish the energy that we need is produced by chemical action.

Heat developed by the passage of an electric current through a wire will be studied in detail in a later chapter. This heat is used for many different purposes.

Summarizing, we can say that the chief sources of heat are: (1) the sun, directly or indirectly, (2) friction, (3) compression, (4) the breaking down of radio-active substances, (5) collision, (6) chemical action, and (7) electricity.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

anthracite
bituminous
carbon dioxide
carbon monoxide
carboniferous age
charcoal
coal gas
coal tar
coke
collision
compression
friction
fuel
hydrocarbon
marsh gas
naphtha
petroleum
radio-active
temperature
volatile

Write the number of each item on your paper, and after it the word that completes the statement.

1. Heat is a form of ________.
2. Substances used to produce heat by burning are called ________.
3. When carbon in a fuel burns, heat and ________ are produced.
4. Coke is produced when ________ is heated in the absence of a supply of air.
5. The normal temperature of the body is ________.
6. Heat in the body is produced by ________.
7. Most of the coal in the earth was formed during the ________ age.
8. Smoke is unburned ________.
9. Most of the heat generated in a well-oiled bicycle pump is produced by chemical action; compression; energy; friction.

Which item in each of the following lists does not belong with the others?

10. petroleum; hydrocarbon; limestone; marsh gas; naphtha.
11. potassium chlorate; dynamite; match; phosphorus; sulphur.

Which of these statements are true? If any are false, re-state them in correct form.

12. Charcoal is partially burned bituminous coal.
13. Carbon dioxide burns with a light blue flame.
14. When a gas is compressed it becomes cooler.
15. All heat is produced by burning substances.

CHAPTER XX

HOW DOES HEAT SERVE MAN?

Do you know:

In what ways heat serves man? How changes in temperature are measured? What effect heat has on metals? Whether engineers make allowance for changes in temperature in building steel bridges? Why telephone and telegraph wires are slack in summer and taut in winter?

How molecular activity is changed when a substance is heated or cooled? What causes a pitcher to crack if water freezes in it? That no matter how much heat is applied to boiling water in an open vessel the temperature of the water does not rise? Why melting ice cools the interior of a refrigerator?

That heat can be transferred? How heating systems work? The most effective way of ventilating a room?

PROBLEM: HOW IS TEMPERATURE MEASURED, AND WHAT IS THE UNIT OF HEAT?

Is heat one of man's servants? Directly or indirectly, heat is one of man's most necessary servants. Heat is essential to the growth of all plant and animal life. In winter and sometimes in summer we need heat to regulate the temperature in our houses so that living conditions may be comfortable and healthful. Many industries, such as the iron and steel industry, are dependent largely upon heat. Before we can study how heat is used as one of our most necessary and useful servants, we must first determine how temperature and heat are measured.

How is temperature measured? The *temperature* of a substance is measured by means of a thermometer. Because a liquid expands when heated, we can measure a change in temperature by measuring the amount of expansion of a liquid. This is the principle on which the thermometers in common use are based. Usually a small amount of a liquid, such as mercury, is placed in a glass bulb from which a tube extends. When the thermometer is placed in a warm place, the mercury expands and rises in the tube. By marking a scale on the tube, temperatures can be read. The two scales in use in the United States are the Fahrenheit and the centigrade scales (Fig. 211).

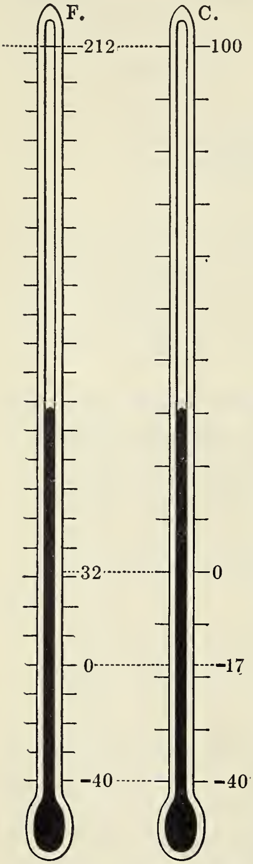


FIG. 211. Would a rise of 1° on the centigrade scale be greater or less than a rise of 1° on the Fahrenheit scale?

The Fahrenheit scale was made in 1714 by a German scientist named Fahrenheit. He chose for his zero point the temperature at which a saturated salt solution freezes. On this scale the freezing point of pure water is 32° and its boiling point is 212°. The Fahrenheit thermometer is the one we use in everyday life. It is also used by the United States Weather Bureau and by doctors and nurses.

The centigrade scale was first made by Celsius, a Swedish astronomer, in 1742. This scale is so named because there are one hundred degrees between the freezing point of pure water (0° C.) and its boiling point (100° C.) (Fig. 212). Because this interval between the freezing and boiling point of pure water is 100 degrees (and therefore easily divisible into smaller intervals of ten degrees), the centigrade scale is better adapted to scientific work than the Fahrenheit. The centigrade scale is used almost universally for scientific work; you will find it referred to very generally in scientific books and magazine articles. The centigrade thermometer is also in everyday use in many European and South American countries.

How can you change temperature readings from one scale to the other? In Figure 211, what is the freezing point of pure water on the Fahrenheit scale? What is its boiling point? How many degrees are there between these two points? From the figure find the number of degrees between the freezing and boiling points of pure water on the centigrade scale. Does one degree Fahrenheit represent a smaller or a larger change of temperature than one degree centigrade? Why? Since 100 centigrade degrees are equal to 180 Fahrenheit degrees, then 100° C. = 180° F. and

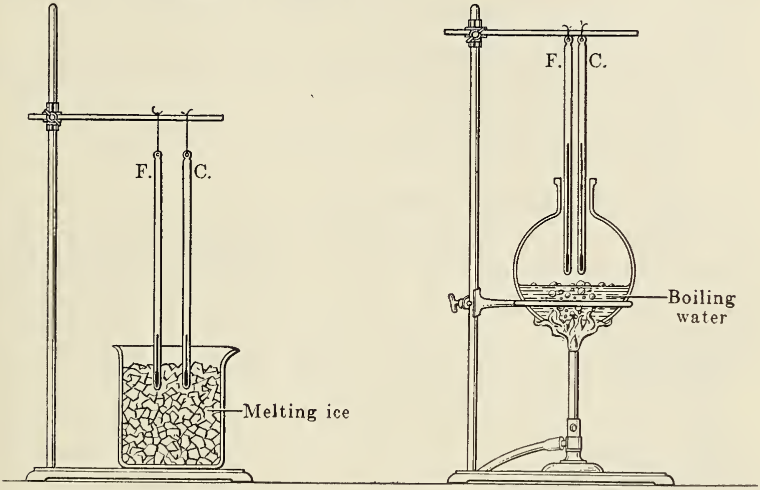


FIG. 212. From this drawing explain how the freezing point and the boiling point of pure water are determined for each thermometer.

$1°\text{ C.} = \frac{180}{100} = \frac{9°}{5}\text{ F.}$; also $180°\text{ F.} = 100°\text{C.}$ and $1°\text{ F.} = \frac{100}{180} = \frac{5°}{9}\text{ C.}$

For each degree of centigrade change, then, there will be $\frac{9}{5}$ degrees of Fahrenheit change. A change of 20° C. will be the same as a change of $\frac{9}{5} \times 20$ or 36° F. Then if the temperature is 20° C. above freezing, it will be 36° F. above freezing. This temperature would be represented on the centigrade scale at the point 0° + 20°, or just 20° C. On the Fahrenheit scale this temperature would be represented at the point 32° + 36°, or 68° F.

Notice that it was necessary to add 32° in finding the Fahrenheit reading in terms of centigrade. Why? Explain why it was not necessary to add anything in finding the centigrade reading from Fahrenheit.

The work shown above leads to the formula for changing a centigrade reading to a Fahrenheit reading:

$$\text{Fahrenheit reading} = \tfrac{9}{5}\ \text{centigrade reading} + 32°,$$
$$\text{or F.} = \tfrac{9}{5}\,\text{C.} + 32°.$$

Using this formula, we may change 30° C. to a corresponding Fahrenheit reading as follows:

$$\text{F.} = \left(\frac{9}{5} \times 30°\right) + 32°;\ \text{F.} = 54° + 32° = 86°$$

To check this result use Figure 211.

To change a Fahrenheit reading to a centigrade reading, it is necessary (1) to subtract 32° from the number of degrees Fahrenheit and (2) multiply the difference by $\frac{5}{9}$; this gives us the following formula:

$$\text{Centigrade reading} = \tfrac{5}{9}\ (\text{Fahrenheit reading} - 32°),$$
$$\text{or C} = \tfrac{5}{9}\,(\text{F.} - 32°).$$

Using the formula, we may change 113° F. to the corresponding centigrade reading as follows:

$$\begin{aligned} \text{C} &= \tfrac{5}{9}\,(113° - 32°) \\ &= \tfrac{5}{9} \times 81° = 45°\ \text{C.} \end{aligned}$$

Special problem. The temperature at which a schoolroom should be kept is 68° F. What would a centigrade thermometer read at this temperature?

Body temperature is 98.6° F. What would this temperature be if registered on a centigrade thermometer?

At sea level the temperature at which 1 cubic centimeter of water weighs 1 gram is 4° C. What is this temperature on a Fahrenheit thermometer?

What liquids are used in thermometers? Since mercury freezes at 39.7° C. below zero and boils at 357° C., at normal atmospheric pressure, we could not measure a temperature lower than −39.7° C. or higher than 357° C., if wholly dependent on a mercury thermometer. For the measurement of very low temperatures, alcohol, which has a freezing point of −130.5° C., is used instead of mercury. For the measurement of very high temperatures, an air thermometer or a pyrometer, an electric device, is used.

Experiment 88. To make an air thermometer. Fit a Florence flask with a one-hole rubber stopper and pass a glass tube about 18 inches long through the stopper. Invert the flask and tube (Fig. 213) over a dish of water. Put a bit of potassium permanganate in the water to color it.

To show what would happen should the temperature be increased, heat the flask carefully with a Bunsen burner until a few bubbles appear in the water. Withdraw the burner. As the air in the flask cools, note that the colored water rises in the tube. When the air in the flask has reached room temperature, put the palm of your hand on the flask. What happens? Is an air thermometer very sensitive? Did the temperature of your hand affect it?

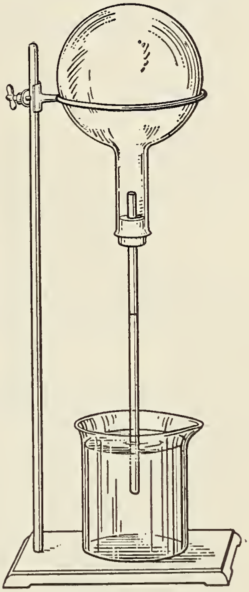


FIG. 213. An air thermometer.

What unit is used in measuring heat? The unit for measuring heat is the calorie. A *calorie* is the amount of heat required to raise the temperature of one gram of water one degree centigrade.

For example, the amount of heat required to raise the temperature of one gram of water from 20° C. to 21° C. is one calorie. How many calories would be required to raise the temperature of two grams of water from 20° C. to 21° C.? To raise the temperature of two grams of water from 30° C. to 32° C.? Also, the amount of heat that must be withdrawn from one gram of water to reduce its temperature from 21° C. to 20° C. is one calorie. How much heat must be withdrawn from four grams of water to reduce its temperature from 25° C. to 20° C.?

In general, then, to find the number of calories needed to raise or lower the temperature of a given weight of water a certain number of degrees, multiply the number of grams of water by the number of degrees centigrade the temperature is to be raised or lowered.

PROBLEM: HOW DOES HEAT AFFECT THE VOLUME OF SOLIDS, LIQUIDS, AND GASES?

Experiment 89. To show how heat affects iron. Procure the iron ball and ring apparatus shown in Figure 214. The ball was made just large enough to pass through the ring, when they are both at the same temperature. Heat the ball with a Bunsen burner. Will the ball pass through the ring now? Place both ball and ring in the flame for a minute. Will the ball pass through the ring? If the ball should pass through the ring, let it remain there for about half a minute and then attempt to withdraw it. What happens? Finally, after about one minute, again attempt to withdraw the ball. What happens now? Explain. What happens to iron when it is heated? What happens when it cools?

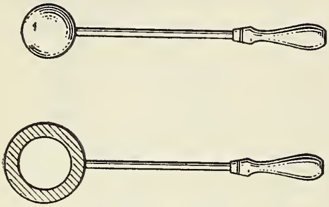


FIG. 214. Ball and ring apparatus.

Do metals expand and contract with changes in temperature? You found that the iron ball expanded when it was heated and contracted when cooled. Other experiments show that nearly all metals expand when heated and contract when cooled.

Experiment 90. To show that an iron rod increases in length when heated. Arrange an iron rod on two wood blocks or chalk boxes (Fig. 215) so that one end rests on a small wire bent to form a pointer. Heat the rod and watch the pointer. Whan happens to the pointer when the rod is heated? Does the iron rod expand when heated? Using care not to jar the table, remove the flame and again notice the pointer. What happens? Did the iron rod contract when cooled?

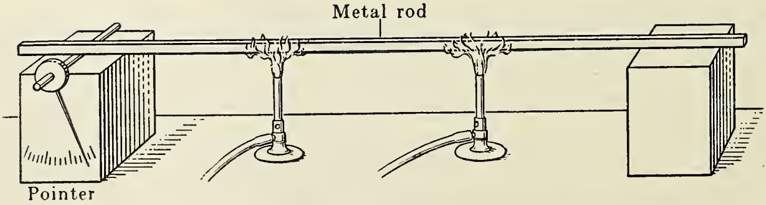


FIG. 215. When the rod is heated what happens to the pointer?

In engineering work involving metals their expansion and contraction must be taken into consideration. Allowance for this expansion and contraction is made at the joints of bridges, in laying the rails of a railroad, in erecting large steel buildings, and in making engines and machinery. In manufacturing electric light bulbs a specially prepared metal, having the same rate of expansion as glass, is used for the wires which conduct the electric current through the glass, thus preventing the glass from being broken.

How does a thermostat operate? The operation of a *thermostat*, a device often used to regulate the draft in a furnace, depends upon the expansion and contraction of metals. Figure 216 illustrates the way a thermostat operates. The vertical bar, which is made of two metals—brass and iron—is a part of two electric circuits.

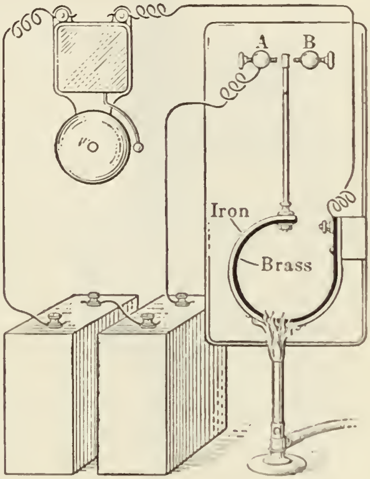


Fig. 216. Apparatus to illustrate the operation of a thermostat.

As the temperature of the room rises, the brass and iron both expand; they do not, however, expand at the same rate, and this unequal expansion causes the vertical bar to move over toward *A*. If the temperature rises enough to bring the vertical bar into contact with *A*, an electric circuit is closed and the draft of the furnace is turned off automatically by a motor. Should the temperature fall, the brass will contract more rapidly than the iron, and the vertical bar will move toward *B*. Should the bar reach *B*, it will close another circuit which automatically opens the draft of the furnace. The principle of the thermostat is used in many other regulating devices, such as oven thermometers, flash lamps on electric signs, "warm" and "cold" bells in hothouses, and even in the balance wheel of a watch.

Do liquids expand and contract with changes in temperature? Liquids, like solids, expand when heated and contract when cooled. This may be observed in thermometers, as the mercury or alcohol rises or falls with changes in temperature.

Experiment 91. To show how a given volume of water is affected by a change in temperature. Fit a flask with a two-hole rubber stopper. Through one hole of the stopper put a glass tube thirty inches or more in length and through the other hole a thermometer (Fig. 217). Fill the flask with water and place the stopper in the flask in such a way that water rises in the tube one-half inch above the stopper.

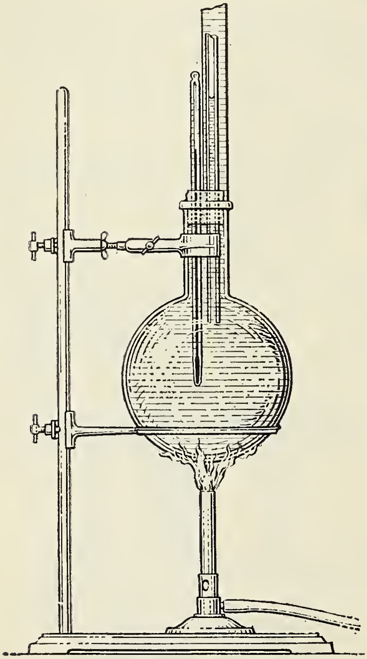


FIG. 217. Water expands for each degree its temperature rises.

Heat the flask gently. As the water is heated, watch the water in the tube. What happens? The height of the water in the tube may be measured with an ordinary meter stick.

Let one pupil read the thermometer and another the height of the water. Announce to the class the reading for every five degrees that the temperature rises. The class should record the data given. The table below suggests a form for the record.

Readings	*Degrees*	*Centimeters*
1	25	?
2	30	?

The readings should continue until the water has reached the top of the glass tube. The water in the flask should be heated slowly and it should not be allowed to reach the boiling point. Does a given volume of water expand in volume with a rise in temperature?

Withdraw the heat and allow the water to cool. Observe the water in the tube. What happens? Does a given volume of water contract in volume with a fall in temperature?

Special problem. How is a given volume of water affected by heat? Draw a graph, using the data from Experiment 91, to show the relationship between the rise in the height of the water in the tube and each rise of five degrees in temperature. Plot the height in centimeters on the vertical axis and the temperature readings on the horizontal axis.

Experiment 92. To show that a given volume of air is affected by a change in temperature. Fit a Florence flask with a one-hole rubber stopper. Put a glass tube about twenty inches long through the stopper. Clasp both hands over the flask firmly and hold the end of the glass tube in a dish of water. What happens? Explain. Now gently heat the flask (Fig. 218). What happens? Explain.

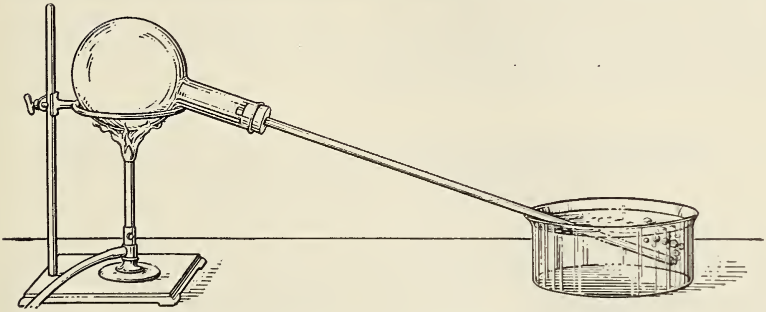


FIG. 218. A gas expands when heated. Explain.

Allow the flask to cool, keeping the end of the glass tube beneath the surface of the water. What happens? Explain. How does the increase in the volume of the air compare with the volume of water that ascended the tube? Explain. Does a given volume of air expand with a rise in temperature? Does a given volume of air contract with a fall in temperature?

Why do gases expand and contract with changes in temperature? Review Experiment 88. Gases show a very uniform expansion in volume when heated in a container which allows them to expand freely. This expansion and contraction of gases is explained by molecular activity.

When a gas is heated, the molecules of the gas move faster and faster. If the molecules cannot move farther apart because the gas is in a closed container, they hit the walls of the container harder and more often and consequently increase the pressure upon its walls. From the point of view of the transformation of energy, this increased molecular activity is due to the fact that the heat energy is changed into kinetic energy.

When a gas is cooled its molecular activity decreases, and in consequence the molecules come closer together. This decrease in molecular activity, then, either causes the gas to decrease in volume if the pressure remains the same or reduces the pressure if the volume remains the same. This decrease in molecular activity is due to the fact that the kinetic energy of the molecules has been changed into heat energy.

PROBLEM: HOW ARE SOLIDS AND LIQUIDS AFFECTED BY CHANGES IN TEMPERATURE?

What are fusion and solidification? When a metal such as copper is heated, the molecules begin to move more rapidly. They also move farther apart. As a result, heating makes the copper expand. If the heating is continued, the molecules move still farther apart and still more rapidly until the copper becomes a liquid. This change from solid to liquid form is called *fusion*; other terms used for fusion are liquefaction and melting. The reverse process, i.e., the change from a liquid to a solid, is known as freezing or solidification.

You know that the melting point of ice and the freezing point of pure water are the same, 32° F. or 0° C. Other substances have different melting points, but the temperature at which any one substance melts or solidifies is always the same.

Melting Points of Some Common Substances

Alcohol	–130.5° C.	Lead	327° C.
Mercury	–39.7° C.	Zinc	419.4° C.
Ice	0° C.	Silver	960.5° C.
Paraffin	55° C.	Copper	1083° C.
Tin	231.9° C.	Iron	1530° C.
Platinum	1775° C.		

Do all liquids decrease in volume on solidifying? Most liquids decrease in volume when they solidify, but the opposite is true of water, type metal, and a few other substances. With these, there is a sudden marked increase in volume at the moment of solidification; e.g., water in freezing increases in volume about nine per cent. The force of its expansion is so great that it breaks water pipes, steel containers, and even rocks.

The melting point of an alloy is not necessarily the same as the average of the melting points of the metals in the alloy. The melting point of tin is 231.9° C. and that of lead 327° C., while the melting point of solder, the common alloy of these two metals (50% tin and 50% lead), is 188° C.

Experiment 93. What becomes of the heat used to melt ice? Place a centigrade thermometer in a pan containing melting ice or snow. After two minutes read the thermometer. What is the reading? Heat the pan very, very slowly, keeping the thermometer from touching the bottom. While the ice or snow continues to melt read the thermometer again. What is the temperature reading now? Is there a change in temperature? Continue to heat the pan until the ice or snow is all melted. What is the temperature reading now? Continue to heat the water. What change in temperature do you notice now?

This experiment shows that heat is required to change ice or snow into liquid form. The thermometer did not indicate a rise in temperature until all the ice or snow had been melted. The heat that changes ice or snow at 0° C. into water at 0° C. is known as *heat of fusion;* heat of fusion increases the activity of the molecules of the ice or snow until they are melted.

Since about eighty times as much heat is required to melt a gram of ice as it does to raise one gram of water 1° C., we say it requires approximately eighty calories of heat to change one gram of ice at 0° C. to water at the same temperature. The heat of fusion of ice or snow is eighty calories (exactly 79.6 calories).

How does ice keep a refrigerator cold? The refrigerator using ice is a box constructed with double walls that hinder the passage of heat. When ice is placed in one of the upper compartments it begins to melt. The eighty calories of heat required to melt each gram of ice are taken from the air inside the refrigerator, from its inner walls and from its contents, thereby reducing the temperature in the refrigerator. Figure 219 indicates the movement of air currents in a refrigerator. To keep foods from spoiling until used the temperature should be 50° F. or lower.

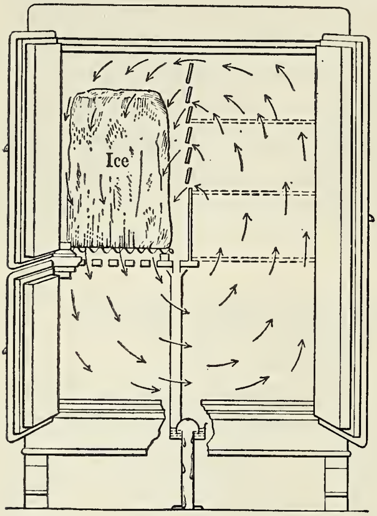


FIG. 219. If the ice in this refrigerator were in the upper right-hand corner, what would be the direction of the air currents?

Special problem. To study the temperature of a refrigerator. Place a thermometer in your refrigerator at home and close the door. After ten minutes take a reading of the thermometer. Change the thermometer to another position in the refrigerator, close the door, and after another ten minutes take a second reading. What is the average for the two readings? Is the refrigerator in your home in good working condition? How do you know?

Experiment 94. To show the vaporization of water. Heat a beaker of water. Watch the water as it approaches the boiling point. Where do the bubbles come from that gather on the walls of the beaker? Do the bubbles in the water become smaller or larger as they rise in the water? What becomes of the water that disappears?

What is vaporization? If we continue to heat a liquid, the molecules of the liquid move faster and get farther apart until they escape into the air. As you already know, the changing of a liquid into a gas is known as *vaporization.* Slow vaporization, that is, evaporation, takes place only at the surface of a liquid.

As a liquid continues to be heated, it finally reaches a temperature at which molecules of the liquid below the surface change into vapor. This change is called *boiling.* The bubbling of a boiling liquid is caused by bubbles of its vapor as they approach the surface of the liquid and escape.

Evaporation of a liquid takes place at all temperatures, but it boils at one temperature only. This temperature is known as the *boiling point* and it varies according to the pressure of the atmosphere on the liquid. Would the boiling point of a liquid be higher or lower in Denver than in New York City? Why? If the pressure on a liquid does not change, the temperature of the boiling liquid will not change until all of the liquid is vaporized.

The table below gives the *boiling points*, or temperatures at which some common substances change from the liquid to the gaseous state at normal air pressure.

Ether	35° C.	Water	100° C.
Chloroform	61.2° C.	Mercury	356.9° C.
Alcohol	78.4° C.	Sulfur	444.6° C.
Benzine	80.4° C.	Zinc	907° C.

Experiment 95. To show whether water changes in temperature while boiling. Boil some water in a Florence flask and place a thermometer in the water. Continue to boil the water, reading the thermometer once a minute for several minutes. Does the water change in temperature? Can you account for the fact that although heat was applied continually to the boiling water its temperature did not rise?

What is heat of vaporization? Experiment 94 shows that heat is required to change water into steam. In general heat is required to change a liquid into a gas. Experiments have shown that 536 calories are required to change one gram of water at 100° C., into steam at 100° C.

How many calories are required to change 20 grams of water at 100° C., into steam at 100° C?

In the reverse process, that is, the condensation of one gram of steam at 100° C. to water at the same temperature, 536 calories are given off. The fact that steam gives off so much heat in condensing into water is the chief reason why steam is used to heat buildings. The heat required to change water in a boiler into steam is given off when the steam condenses in the radiators. We can better understand why a radiator furnishes so much heat if we remember that for each gram of steam that condenses 536 calories are released. The amount of heat required to change one gram of liquid at its boiling point to vapor at the same temperature is called *heat of vaporization.*

If 100 grams of steam at 100° C., condense into water at 100° C., how many calories are given off?

Experiment 96. To show how a decrease in air pressure affects the boiling point of water. Boil some water in a flask. Remove the flask from the flame and place it under the receiver of an exhaust pump (Fig. 220). Exhaust some of the air by working the pump vigorously. What happens to the water in the flask? Does the water begin to boil again when evidently it is much cooler than it was when boiling over the flame?

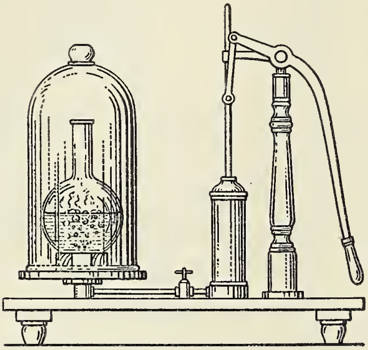


FIG. 220. How is water made to boil at a temperature below 100° C.?

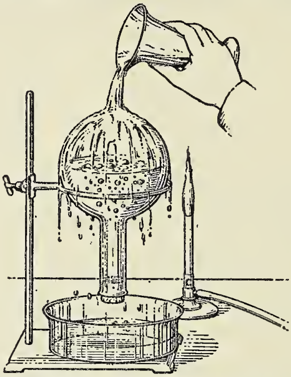


FIG. 221. Does this water boil below 100° C. for the same reason that it did in Fig. 220? Explain.

Experiment 97. To show that water can be boiled at a lower temperature than 212° F. Fill a Florence flask half full of water and boil the water vigorously for a minute. Now remove the heat and close the flask with a stopper. Invert it on a ring stand (Fig. 221) and pour cold water over it. The water in the flask will boil again vigorously. Why? After the water stops boiling, remove the stopper and take the temperature of the water. At how low a temperature can you boil water in this way?

In both of these experiments you observed that the boiling point of water is lowered if the pressure of air upon the water is decreased. In consequence we should expect the boiling point of water at the top of a high mountain to be lower than at sea level. Why? This is exactly the case. In the city of Quito, Ecuador, when water is heated to 90° C. it starts to boil; on the top of Pike's Peak water boils at 89° C.; and on the top of Mount Blanc at 84° C. Would it take more fuel to cook potatoes by boiling, on the top of Pike's Peak or at sea level? Why?

PROBLEM: HOW IS HEAT TRANSFERRED FROM PLACE TO PLACE?

Can heat be transferred from one place to another? Fortunately, for our comfort, heat can be transferred from one place to another. The whole of a large room may be heated by a stove or a fireplace; a whole house may be heated by a single furnace; or a number of buildings may be heated from one central heating plant. Indeed, we receive heat from the sun because heat can be transferred.

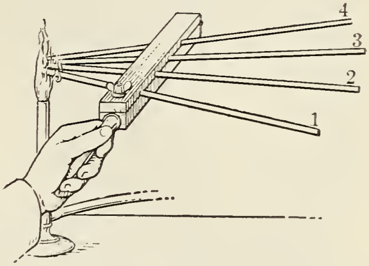


FIG. 222. How may you discover the conductivity of each of several metals?

Experiment 98. To show that heat is transferred by conduction. Attach to a board (Fig. 222) several wires of the same length and diameter but of different materials—for example, copper, brass, iron, and German silver. Hold the ends of the wires in a Bunsen flame. Touch the other ends of the wires. Which wire becomes hot first? Second? Third? Fourth? Does the heat travel at the same rate in the wires? In which did it travel the fastest? Which wire is the best conductor of heat?

Test a glass rod and an iron rod to see which is the better conductor of heat.

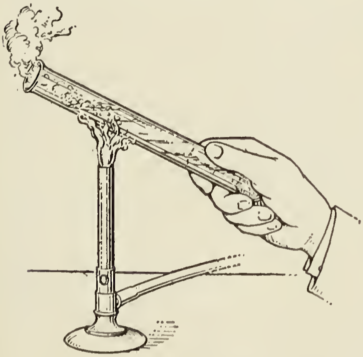


FIG. 223. Is water a good conductor of heat?

Experiment 99. To show that water transfers heat very slowly by conduction. Fasten a weight to a small piece of ice so that it will remain at the bottom of a test tube full of cold water. Hold the lower part of the tube in your hand and heat the upper part of it with a Bunsen flame (Fig. 223). How long did you hold the tube in the flame before heat was transferred to your fingers? How long did you boil the water in the upper part of the tube before the ice melted? Do you conclude from this experiment that water is a good or poor conductor of heat? Is the glass of the test tube a good or poor conductor of heat?

Experiments 98 and 99 prove that certain materials transfer heat by *conduction* more rapidly than others. Metals conduct heat readily. Silver, which transfers heat by conduction more readily than any other metal, is the standard used to measure the heat conductivity of other substances. If the conductivity of silver is considered to be 100, the conductivity of other materials can be represented by the numbers given in the following table.

Silver	100	Zinc	19	German silver	6.2
Copper	74	Tin	15	Ice	.21
Gold	53	Iron	12	Glass	.15
Aluminum	48	Lead	8.5	Hard rubber	.04
Brass	25				

Other experiments prove that certain materials, such as wood and hard rubber, are poor conductors of heat. In general, liquids are poor conductors of heat. Gases, such as air, are also very poor conductors of heat. This explains why garments of wool or fur keep us warm; the dry air which fills the spaces in wool or fur makes the transfer of heat from the body difficult, thus keeping the body warm.

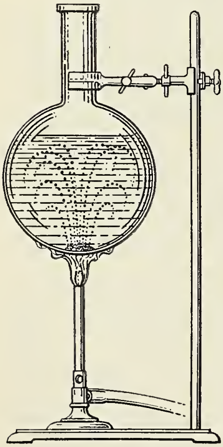


FIG. 224. Explain how the flame heats the water and starts convection currents in the flask.

Although it is necessary that the materials used to make cooking utensils, radiators, soldering implements, flatirons, and also the walls of stoves or furnaces, should be good conductors of heat, we have many uses in everyday life for materials that are poor conductors of heat. For instance, we surround our heating pipes with asbestos (a very poor conductor) so that the heat in the pipes may not be transferred by conduction to the air; and we use a wooden handle on a flatiron so that the heat of the iron may not be transferred to the hand.

How is heat transferred by convection? If water and gases transfer heat poorly by conduction, how is it possible, then, to heat a pan of water or the air in a large room?

Experiment 100. To show that convection currents are set up in water when it is heated. Pour water into a Florence flask until it is two-thirds full. By means of a thistle tube, or other glass tube, place a few bits of potassium permanganate in the bottom of the flask. Heat the bottom of the flask with the tip of the flame. The coloring matter will show what is going on inside the flask (Fig. 224). Have currents been set up in the heated water? How do you know?

In the experiment just performed, as the water at the bottom of the flask became heated, it expanded and thereby became lighter than the surrounding water. The heavier, cold water forced the lighter warm water upward, thus forming the currents indicated by the movements of the colored water. As the flame continues to heat the flask, more heavier cold water becomes warm and expands. This process continues until all of the water is heated to the same temperature. As you can see when matter is transferred from one place to another, the heat that it contains is transferred with it.

The currents produced in liquids and gases by heating are called *convection currents*, and the transfer of heat by convection currents is called *convection*.

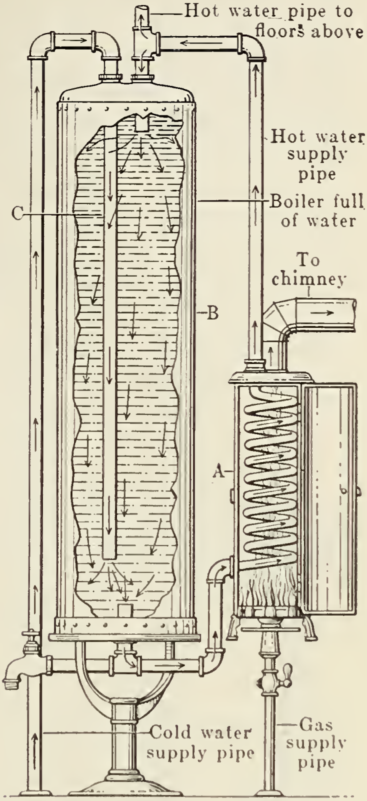


FIG. 225. Explain how cold water is changed into hot water by this hot-water boiler and heater.

How is the principle of convection used to heat water for use in the home? Figure 225 is a vertical section of a kind of hot water heater used in homes. The heater *A* contains a copper or iron coil connected with tank *B*. When the heater is lighted, the water in the coil is heated and begins to move through the coil, pipes, and boiler in the direction of the arrows. Why? This movement of water continues until the temperature of the water in the tank is the same everywhere. Why? The hot water pipe leads from the top of tank *B* directly to the faucets. When hot water is drawn from a faucet, therefore, it flows from the top of the tank. Why? At the same time an equal volume of cold water flows through pipe *C* into the tank at the bottom. After hot water has been drawn out and cold water admitted, the heater again heats the water as before.

Special problem. Convection in gases. Draw a diagram to show the convection currents set up in the air in a room by a fireplace. Explain how the air in all parts of the room becomes warm.

Recall what you have learned about wind systems. Explain the trade winds as convection currents.

Heat is transferred by radiation. Let us see whether conduction and convection will explain all the ways by which heat is transferred. If you hold a heated iron near your face, heat is transferred to your face at once. It could not be transferred by conduction because air is such a poor conductor. Neither could it be transferred by convection because the convection currents would move upward. Why? Similarly, when standing in front of a fire, heat is transferred to your body but neither by conduction nor by convection. Why? Consequently there must be another way by which heat is transferred.

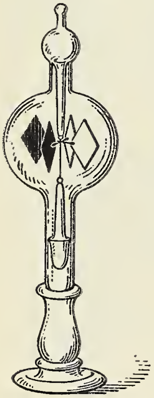


FIG. 226. A radiometer is a vacuum tube in which vanes rotate when heat energy falls upon them.

Experiment 101. To show that heat is transferred by radiation. Heat the ball of the ball-and-ring apparatus or any other metal object. Bring it close to a radiometer (Fig. 226). What happens? Why?

Does this experiment show that a heated object sends out heat energy? This heat energy travels in straight lines and is not affected by convection currents or the poor conductivity of air or glass.

When rays of heat travel through space, in straight lines from the heat-giving surface, we say that the heat is transferred by *radiation.*

Is heat transferred by one way alone? You should remember that heat is seldom transferred in only one way. For example, a fire in a fireplace heats the air of the room mainly by the convection currents which are set up. In addition, the fire radiates some heat directly into the room. The fire also heats the substances with which it comes in contact. If it is built on a grate, the grate becomes hot by conduction; if it is stirred with a poker, the poker becomes hot by conduction; the bricks in the fireplace become hot by conduction. These heated substances, of course, set up convection currents and also radiate heat.

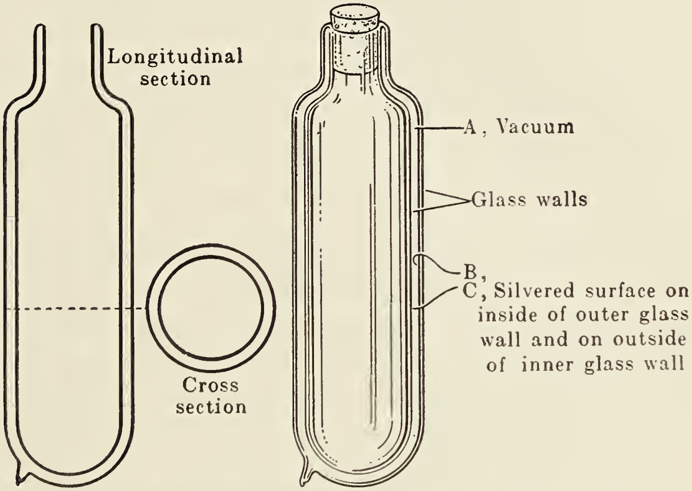

Longitudinal section
Cross section
A, Vacuum
Glass walls
B,
C, Silvered surface on inside of outer glass wall and on outside of inner glass wall

FIG. 227. How is it possible for a thermos bottle to keep a hot liquid hot or a cold liquid cold?

How does a vacuum bottle "work"? The vacuum bottle, used to keep warm liquids warm and cold liquids cold, is designed to prevent the transfer of heat either by conduction, convection, or radiation. Figure 227 shows the construction of a vacuum bottle. It is made of two glass bottles fused together at the top, with a space *A* between them, from which air is exhausted. Through this partial vacuum, neither heat nor cold is readily transferred either by conduction or convection. Why? Why are vacuum bottles made of glass instead of a metal?

By covering surfaces *B* and *C* (that is, the inside surface of the outer glass bottle and the outside surface of the inner glass bottle) with silver, the liquid in the vacuum bottle cannot radiate heat to the outside and heat from the outside air cannot be radiated into the bottle. So perfectly does a well-made vacuum bottle prevent the transfer of heat or cold that a liquid in it remains at nearly the same temperature for several hours.

How is a thermos jug constructed? A thermos jug is constructed of an earthenware jug, which is a poor conductor of heat, placed inside a metal container. Between the earthenware jug and the metal is inserted a material (cork), which not only is a poor conductor of heat but also prevents the transfer of heat by convection currents in the space between the jug and the metal. On account of the kind of material used, transfer of heat by radiation is also reduced to a minimum. While a jug of this kind is not so efficient as a vacuum bottle, it will keep a liquid at about the same temperature for a few hours.

Problem: How Is Heat Transferred in Cooking and in Heating Our Houses?

How is heat used in cooking? Heat is transferred in three ways in cooking. If a pan of water is placed on a heated stove the bottom of the pan is heated by radiation and conduction. Explain. The water in contact with the bottom of the pan is heated by conduction, and convection currents are set up in the water until all the water is heated. Potatoes placed in this hot water are heated by conduction.

How is a room heated by a fireplace? The air in a fireplace becomes lighter as it is heated and is forced up the chimney by the colder and heavier air. Since few of our houses are air-tight, the colder air outside of the house forces its way in through spaces around the windows and doors to take the place of the air which, when heated, was forced up the chimney. In this way a great deal of fresh air comes into the house; at the same time as much as ninety per cent of the heat from the fireplace is carried out through the chimney by convection currents. Consequently, most of the heat received from a fireplace is due to radiation.

Even though a fireplace is an inefficient heater, we still like them in our homes for the cheering effect of the fire and as a source of heat when but little is needed. Until quite recent times fireplaces were the chief means for heating homes and for cooking. They are still used in many parts of the world for heating.

How is a room heated by a stove? Since the fireplace permits so much heat to pass out of the chimney, an improved method of heating was sought. In 1742 Benjamin Franklin invented an iron stove which he placed partly in a fireplace so that the smoke passed out through the chimney. The air circulated about this stove and, when heated, began to move in convection currents through the room until all the air in the room was warmed. Franklin stated that his new stove sent into the room twice as much heat as a fireplace and consumed only one-fourth the fuel.

Stoves which burn gas, coal, wood, or oil are used as heaters where artificial heat is required. Stoves range in beauty and design all the way from black, turret-like monsters sometimes seen in rural schoolrooms to artistically designed heaters.

Stoves for cooking, whether kitchen ranges using coal or wood, or modern gas stoves, play an important part in our life today. In some localities the electric stove is coming into use for cooking. Although an electric range does not furnish heat as quickly as a gas range, it is convenient and clean.

How is a home heated by a "heating system"? A source of heat such as a furnace or boiler, together with a means of distributing heat through a house is called a *heating system*. There are three methods of transferring heat from a heating system: (1) heated air may be transferred by convection through pipes and registers into the rooms; (2) heated water may be transferred by convection through pipes to radiators in the rooms; (3) steam may be forced by its own pressure through pipes to radiators in the rooms.

The hot-air heating system without pipes. A house may be heated by convection currents of air which move from the furnace upward through one large conducting pipe through a large register into one of the living rooms. From this room warm air circulates by convection into adjoining rooms. This kind of heating system is called a *pipeless furnace* (Fig. 228A). If there is an open stairway in the house, convection currents move from the register up to the second floor and return again to the register and so back to the furnace. To heat the entire house, all inside doors must be open. Why? The pipeless furnace is used with success only in a small, compact house. One merit of this kind of heating system is the low cost both of the furnace and its installation.

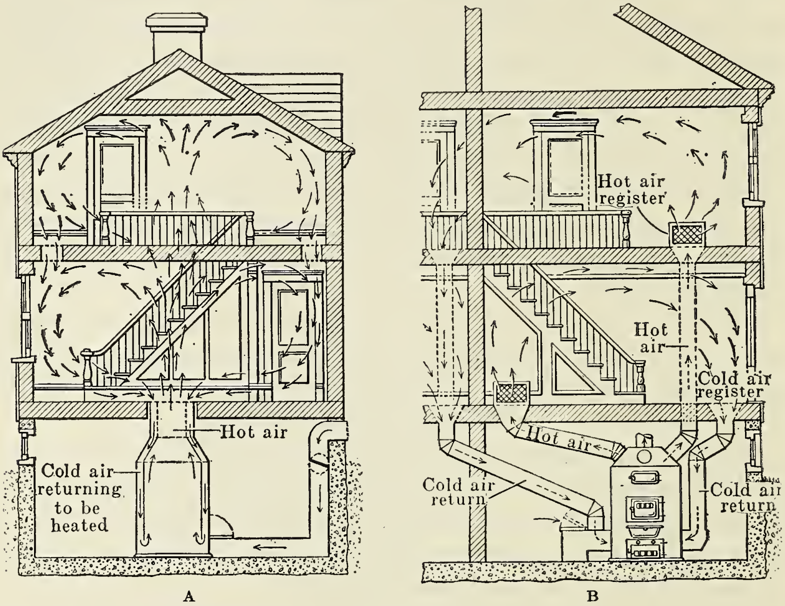


Fig. 228. What kinds of heating systems are installed in these houses? Explain fully how the house on the left may be heated; the one on the right.

The hot-air heating system with pipes. The temperature of the different rooms of a house will be much more constant and uniform, if, instead of transferring heated air from the furnace through just one pipe, several pipes are used (Fig. 228B). Cold air may be supplied to the furnace through an intake from the outside, by the return of the cold air from the rooms above, or it may be taken from the basement. Figure 229 is a vertical section of the furnace in a hot-air system. Explain how it works.

The advantages of hot-air systems are (1) ability to send heat into rooms quickly, and (2) constant circulation of air. The chief disadvantages are the tendency for dust to get into the circulating air, the possibility of gases from the burning fuel passing into the rooms above, and the difficulty of maintaining a fire in the furnace that will keep the temperature of the rooms uniform and constant.

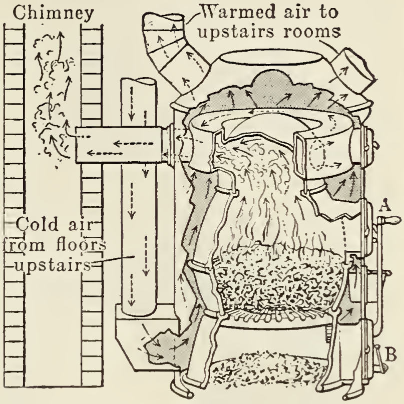


FIG. 229. What prevents smoke from coming up into a house heated by a hot-air furnace?

Heating systems that use hot water and steam. In these systems hot water or steam (water vapor) transfers heat to radiators in the various rooms of the house (Fig. 230). It is difficult to transfer heat by a hot-air system if long winding pipes are necessary, but heat can be transferred by hot water or steam through winding pipes with ease, even to radiators in the most remote rooms of large buildings (Fig. 230). If the conducting pipes are covered with a heat insulating material, little heat is lost from the hot water or steam as it passes from the boiler to the radiators.

In hot-water systems the boiler, pipes, and radiators are completely filled with water. After a fire has been started in the furnace, the water in the boiler becomes heated and begins to circulate by convection through the pipes and the radiators (Fig. 230). A tank near the roof is connected with the system, to provide room for the expansion of the water as it is heated. The circulation continues as long as the water in the boiler is kept warmer than that in the radiators. While it requires some time to heat the radiators of a hot-water system, when once they are heated they retain their heat and can be kept at a constant temperature. The radiator heated by the hot water heats by conduction the layer of air nearest it. This heated air, moving in convection currents, heats the room.

The simplest kind of steam heating system requires a hot fire at first to create sufficient steam pressure in the boiler to force steam up through the pipes and radiators, both of which may be filled with air. The pressure of the steam forces the air out through a valve which opens when the radiator is cold but closes and retains the steam when it is heated.

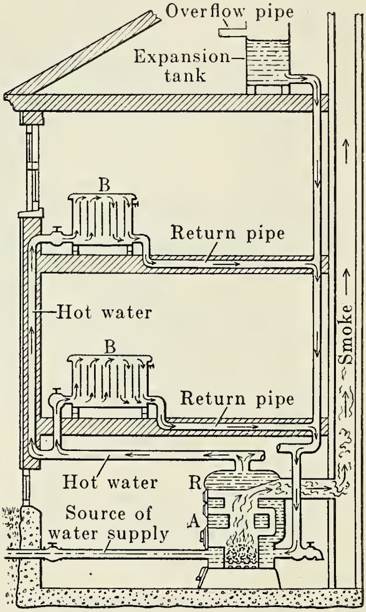


FIG. 230. Hot-water system for heating a house. *A* represents jacket around furnace; *R*, reservoir for hot water; *BB*, radiators. Explain how the system operates.

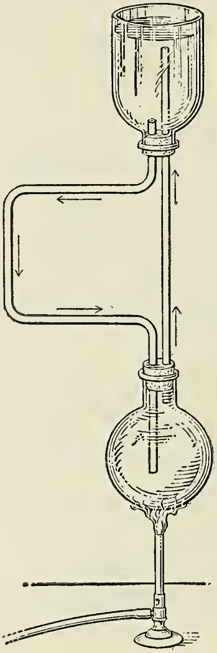


FIG. 231. A study of this apparatus will help you to understand the circulation of water in a hot-water system.

When the steam in the radiator condenses, it returns to the boiler either by the same pipe through which it came to the radiator (the *one-pipe system*), or through a separate return pipe (the *two-pipe system*). However, if the pipes in such a system are not installed in such a way that the water will flow back to the boiler, water may collect in the pipes and the steam as it forces its way through may produce a loud pounding noise.

Explain how the radiator in a steam system heats a room.

The *vapor-vacuum* system is the most highly developed type of steam heating. In the simpler steam heating system the radiators are either hot or cold. In the vapor-vacuum system the amount of heat that enters the radiators can be regulated to maintain a uniform heat. A vapor-vacuum system has an exhaust pump that automatically exhausts air from the pipes and radiators. As a result of this reduced air pressure, water vapor at a lower temperature than 212° F. fills the radiators, and thus the temperature of the radiators is lower than when heated by steam.

What must be considered in heating our houses? In heating a house the problems are: (1) to heat the air in it; and (2) to keep it at the proper humidity. The temperature in a living room should be from 68° to 70° F., and the relative humidity of the air between 50 and 60 per cent.

The cost of installing different kinds of heating systems for a home is in the following order, beginning with the cheapest: (1) pipeless hot-air furnaces, (2) piped hot-air systems, (3) steam, (4) hot water, and (5) vapor-vacuum systems. The cost of operation is exactly the opposite; beginning with the cheapest the order is (1) vapor-vacuum system, (2) hot water, (3) steam, (4) piped hot-air system, and (5) pipeless hot-air furnace.

How should a furnace be operated to avoid smoke? A great deal of fuel can be saved by proper care of a stove or furnace. In the first place, all leaks in the smoke pipe and chimney should be repaired immediately. Why? After coal is shoveled into the furnace, the draft-regulating slides on the feeder door and ash door should be adjusted so as to admit the right amount of air for complete combustion; this is especially necessary when soft coal is used. When the coal begins to burn, gases and free carbon are given off and, if they are not properly mixed with oxygen, they will not be burned but will pass out through the chimney and be wasted. Consequently, the slide in the feeder door *A* (Fig. 229) should be opened enough to furnish sufficient oxygen to burn the gases as they are given off by the burning fuel. After the fire has a good start, the damper in the smoke pipe should be closed at least two-thirds of the way to prevent heat from escaping through the chimney. The correct amount of draft through the ash door *B* can be determined only by experimenting with an individual furnace.

A large fire burning slowly is more economical than a small fire burning rapidly, because a rapidly burning fire produces a strong draft and thereby causes much heat to be forced out through the chimney. Ashes should be taken out of the ash pit every day. If the ash pit is allowed to become full, the draft is obstructed, the fuel is not completely burned, and the grates may be burned out.

Do modern heating systems provide for the proper humidity for bodily comfort and health? Have you ever heard it said that the air in most homes during the winter is as dry as the air over the Sahara? The fireplace lacks any provision for raising the relative humidity of the heated air. When stoves are used, a pan of water should be placed on the stove; this water will slowly evaporate and will raise the relative humidity somewhat. The small reservoir on the side of a hot air furnace should be kept full of water. As the water evaporates, water vapor is mixed with the warm air and carried throughout the house by convection currents.

In modern theaters and department stores the relative humidity of the air is controlled by *air-conditioning* apparatus which not only warms the air in winter and cools it in summer, but also maintains the proper relative humidity for bodily comfort and health. Manufacturers are producing air-conditioning equipment for homes which will make them a more comfortable and healthful place in which to live. Many manufacturing processes (Fig. 232) are dependent for their successful operation on a certain amount of water vapor in the air.

How can a home be ventilated successfully during cold weather? Ventilation of our homes presents a serious problem in cold weather while doors and windows are closed and it is necessary to heat the rooms. Heating with a fireplace provides for ventilation because fresh cold air from outside seeps in through the

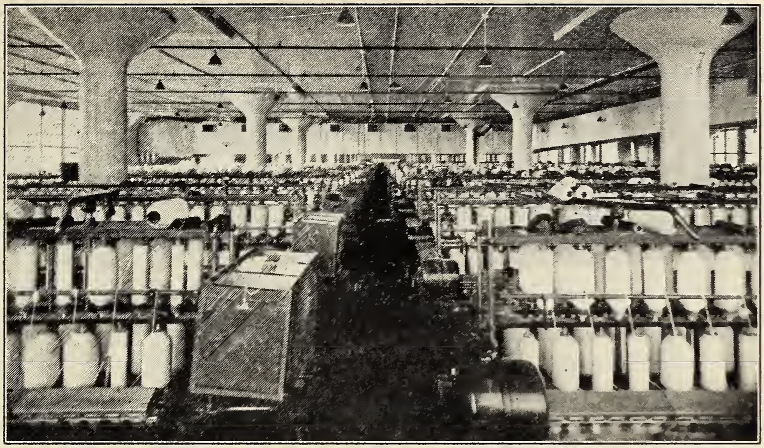


FIG. 232. A cotton mill in New Hampshire in which both temperature and relative humidity are controlled (conditioned). For certain processes in cotton manufacturing not less than a certain amount of water vapor in the air is necessary.

cracks around doors and windows, to take the place of warm air going up the chimney. Why? When a room is heated by a stove, air enters the stove, is heated and passes up the chimney. Consequently the room is ventilated in much the same way as it is when heated by a fireplace.

If a house is heated by a hot-air furnace, it, too, ventilates the home because fresh cold air from out of doors may be heated by the furnace and supplied to the different rooms by means of pipes. If provision is made for enough water vapor to maintain a proper relative humidity, this type of heating system is quite satisfactory.

Both steam and hot-water heating systems are devised to furnish heat only. Ventilation and the proper relative humidity must be secured by entirely separate means.

At the present time various mechanical devices for securing ventilation are connected with heating systems in many public buildings. Recently grave doubts have arisen with respect to their value. In any event it is possible to secure proper ventilation of a home or even a school building by the methods which will now be discussed.

Experiment 102. To show an effective method of ventilating a room. Construct a box like that shown in Figure 233, making it as nearly airtight as you can. The glass front should be removed to permit the candles to be lighted. Place the corks tightly in the holes (the windows tightly shut), light the candles, and replace the glass front. Watch the candles burn. Do they burn briskly or feebly? Why? Do you think the ventilation is good? Fair? Poor? Why?

Now remove the upper row of corks (open the windows at the top). Do the candles burn briskly or feebly? Set fire to some tightly wrapped paper or incense, and hold near the open holes. Watch the smoke. Is much or little outside (fresh) air entering the box? Do you think the ventilation good, fair, or poor? Why?

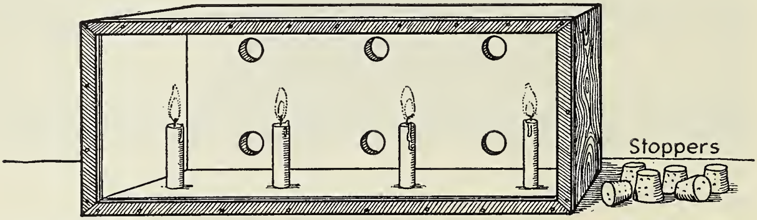


FIG. 233. Using what you learned in connection with Figure 233 tell how your bedroom can be most effectively ventilated.

Replace the upper corks and remove the lower corks (open the windows at the bottom). Do the candles burn briskly or feebly? Hold smoking paper near the open holes. Is much or little outside air entering the room? Do you think the ventilation is good, fair, or poor? Why?

Again remove the upper row of corks (windows open both at top and bottom). Do the candles burn briskly or feebly? Hold smoking paper near the upper row of holes and then near the lower row. Is much or little outside air entering the room? Do you think the ventilation is good, fair, or poor? Why?

Many experiments of this kind have shown that an effective method for ventilating the rooms of a house is to open the windows both at top and bottom.

Special problem. Make a study of the way in which your school room is ventilated. By means of arrows on a drawing indicate how fresh air enters and how other air leaves or is forced out. Do you consider the ventilation satisfactory? Why?

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

air conditioning
calorie
centigrade
conduction
contraction
convection
degree
evaporation
expansion
Fahrenheit
fusion
latent heat
liquefaction
radiation
solidification
thermometer
thermos
thermostat

Write the number of each item on your paper, and after it the word that completes the statement.

1. The amount of heat required to raise the temperature of one gram of water one degree centigrade is called a ________.

2. When ice melts, it ________ about nine per cent of its volume.

3. The thermometer used most in scientific work is the ________.

4. A reading of seventy-seven degrees on the Fahrenheit scale equals a reading of ________ degrees on the centigrade scale.

5. The amount of heat necessary to melt 50 g. of ice at 0° C. is ________ calories.

6. A hot-air heating system depends largely upon the principle of ________ for transferring heat.

7. Heat is transferred from the sun to the earth by ________.

8. The operation of a thermostat depends upon the expansion and ________ of metals.

9. The process of changing a solid to a liquid is called: expansion; vaporization; fusion; solidification; convection.

Which of these statements are true? If any are false, re-state them in correct form.

10. The melting point of an alloy is not the same as the average of the melting points of the metals.

11. It takes less heat to boil water at the top of Pike's Peak than at sea level.

12. When vapors condense, heat is given off.

13. Furs are poor conductors of heat.

14. Water is a good conductor of heat.

THOUGHT EXERCISES FOR UNIT X

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Heat is transferred by radiation.

Questions or Problems

1. Why is wood used to start a coal fire?

2. Why does a fire cause more smoke when first started than it does later on?

3. What becomes of the moisture produced by a flame?

4. Why does a sudden puff of air put out a small flame?

5. Why is a wick a necessary part of a candle?

6. What causes the air in an open flask to become lighter when it is heated?

7. If you place one hand on a rug and the other on a piece of iron in the same room, why does the rug seem the warmer?

8. Which is the better for holding cold drinking water in summer, a silver or a glass pitcher? Why?

9. A green house is sometimes called a trap for heat. Why?

10. How does a thermos bottle keep its contents either hot or cold?

Projects and Reports

1. Plan experiments to demonstrate that heat may be due to friction, compression, electricity, and chemical action.

2. Study the process of manufacturing coal gas. Demonstrate its manufacture by an experiment. Discuss the source of each element found in the composition of this gas.

3. Study the heating plant of your own home, or of the school building. Explain to the class what and how many methods of transferring heat are used in the system.

4. Write to a firm that manufactures furnaces for heating systems. Ask for circulars that show pictures of the furnaces. Report to the class, putting drawings on the board and discussing fully the way the home is heated and how the air is kept at the proper humidity.

5. Plan an experiment to determine the number of calories put into a vessel of water in raising it from room temperature to boiling.

6. Study the process of modern air conditioning and explain to the class the principles connected with the process. Write to a firm that manufactures this kind of equipment, and ask for illustrative circulars.

References for Reading and Study

1. Broadhurst and Lerrigo, *Health Horizons*, Chapter I. Silver Burdett Company.
2. Clark and Small, *The Boys' Book of Physics*, Chapter IX. E. P. Dutton and Company.
3. Collins, A. F., *The Magic of Science.* Chapter VIII. Fleming H. Revell Company.
4. Darrow, F. L., *The Boys' Own Book of Science*, Chapter XXI. The Macmillan Company.
5. Darrow, F. L., *Thinkers and Doers*, Chapter XIX. Silver Burdett Company.
6. Egloff, Gustave, *Earth Oil.* The Williams and Wilkins Company, Baltimore.
7. Harrigan, Paul D., *A B C of Air Conditioning.* Gernsback Publications, Inc.
8. Meister, Morris, *Heat and Health.* Charles Scribner's Sons.
9. Mott-Smith, M. C., *Heat and Its Workings.* D. Appleton-Century Company.
10. Mowry, Wm., and May, Arthur, *First Steps in the History of Our Country*, Chapters I, VII. Silver Burdett Company.

UNIT XI

WHAT IS LIGHT AND HOW DOES MAN MAKE USE OF IT?

Exploring the Realm of Light

When man first appeared on the earth, he depended upon the sun to give him light by day and the moon and stars to give him light and guide him at night. But as soon as tribes began to hold councils at night, it was necessary to have light inside the tent or cave. It is interesting to imagine what man first used for artificial light. History tells us that at different periods of time he burned pieces of wood, animal oil, candles, petroleum oils, natural and artificial gas, and finally he produced light by the use of electricity. As civilization advanced, artificial light played a greater and greater part in our daily life. Buildings were built larger and larger, and while many attempts were made to permit sunlight to enter these structures, many persons spend their entire working day in artificial light. In order to supply our need for light, science has developed lamps which produce light almost the same as sunlight.

When you have looked at a rainbow have you ever wondered how such beautiful colors could be produced? The same light produces the beautiful colors of a sunset and also the brilliance of a diamond. Scientists who have studied light have learned how it may be used to correct imperfect vision, to make a microscope, a telescope, and a motion picture projector.

All of the beauties of nature are due to reflected light. By it we are able to see the green grass and trees and the beautiful colors of flowers. Have you ever wondered why a red dress appears red or why a blue tie appears blue? Man has made use of light to produce color in our public buildings and homes. Our modern world is becoming a world of marvelous color. Wouldn't you like to find out more about this wonderful kind of radiant energy known as light?

CHAPTER XXI

HOW DOES MAN PROVIDE LIGHT FOR HIS DAILY WORK AND PLAY?

Do you know:

What causes darkness? Why sunlight is the best light for your home? Why you cannot see around the corner of a building? What is meant by candle power? That if you are sixteen feet from a light you will receive just one-fourth as much light as another person eight feet from the light? The difference between a transparent and a translucent object?

How a candle is made? How different kinds of artificial light are produced? How light is affected by a gas mantle? That the heating effect of electricity is used to produce light? How a luminous body differs from an incandescent body?

PROBLEM: HOW IS THE BRIGHTNESS OF LIGHT MEASURED, AND HOW DOES LIGHT TRAVEL?

What is the best kind of light? Sunlight is the best light we can have in our homes. It is more restful to the eyes than any form of artificial light. Sunlight is also a protection against harmful germs, especially the germs of typhus and tuberculosis which thrive in a damp, dark place. Houses should be built with sufficient window area in all rooms to allow a plentiful supply of this restful, health-giving light. If you look at an old factory building you will observe that the windows are small and far apart. In modern buildings it is possible with the aid of metal window frames and sashes to provide almost continuous glass walls, through which a large amount of sunlight can enter (Fig. 76). The outer walls of many modern buildings are from fifty to ninety per cent glass. Recent laws governing the construction of school buildings require the window area of each classroom to be equal to at least twenty per cent of its floor area, and the windows so arranged that all the light will enter from one side, preferably from the side to the pupils' left.

Special problem. To determine the ratio of window area to floor area in your school room. Measure the windows and the floor in your school room. Find the ratio of window area to floor area. Is your school room properly lighted?

How is light measured? The unit for measuring the intensity (brightness) of light is the *candle power*. A sperm candle, seven-eighths of an inch in diameter, burning at the rate of 120 grains an hour (slightly more than one-fourth of an ounce an hour) was originally chosen as the source of light of one candle power. The intensity of the light from such a candle at a distance of one foot from it is one *foot candle.*

When we say that an electric light bulb is a 20 candle-power bulb, we mean that it is capable of giving off 20 times as much light as one of these sperm candles. When we say that the brightness of the light on a book is 5 foot candles, we mean that the light on the book is as bright as if the book were one foot away from 5 of these sperm candles. As candles cannot be made which burn always with the same brightness, a light is measured by comparing it with an electric light of known candle power.

Experiment 103. To show how the intensity of light varies according to distance from the source of light. The following apparatus is necessary: a candle, a screen made of a piece of cardboard with an opening one inch square, and a cardboard. Place the screen one foot from the candle and the cardboard two feet from the candle as shown in Figure 234. Measure the length and breadth of the lighted surface on the cardboard. What is its area in square inches? How does this area compare with the area of the opening in the screen?

Move the cardboard so that it is three feet from the candle. What is the area of the lighted surface on the cardboard now? How does this area compare with the area of the opening in the screen?

From this experiment we can conclude that the light which falls on one square inch of surface one foot away from the source of light falls on an area of four square inches when the distance from the source of light is two feet. That is, each square inch of surface receives only one-fourth as much light when the surface is twice as far away from the source.

If the distance from the source is trebled, the object receives only one-ninth as much light on each square inch of surface.

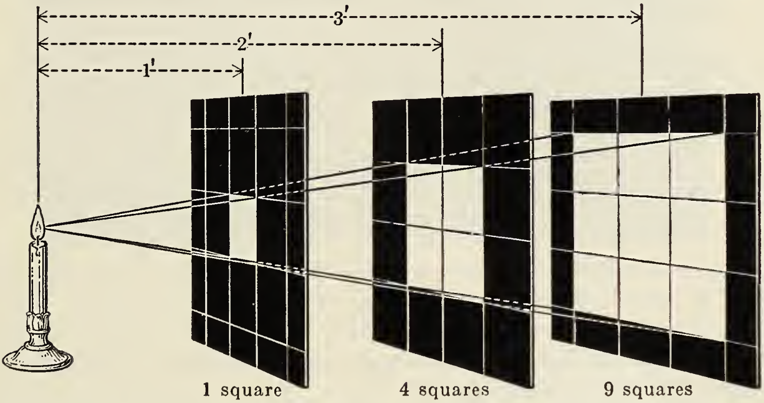


Fig. 234. Explain how this drawing shows that the intensity of illumination varies inversely as the square of the distance from the source of light.

In each case, the ratio may be found by squaring the ratio of the distances. Thus, if the ratio of the distances from the source of light is $\frac{1}{2}$, the object farther from the source receives the square of $\frac{1}{2}$, or $\frac{1}{4}$, as much light. If the ratio of the distances is $\frac{1}{3}$, the object farther from the light receives $\frac{1}{9}$ as much light.

The relation of the intensity of light to the distance from its source helps us to find the candle power of a source of light. Suppose, for example, a sperm candle lights a screen 2 feet away with exactly as bright a light as a lamp 6 feet away. Since the strength of the light depends on the square of the distance from the source, the lamp must be $\left(\frac{6}{2}\right)^2$, that is $\frac{36}{4}$, or 9 times as strong as the candle. But the candle is one candle power. Hence the lamp must be 9 candle power.

Special problem. A sperm candle lights a screen 4 feet away as brightly as a lamp 8 feet away. What is the candle power of the lamp?

Experiment 104. To find the candle power of a lamp. Arrange the apparatus shown in Figure 235. The screen may be made by pasting oiled paper or the front of a transparent envelope over an opening in a cardboard. The candle should be seven-eighths of an inch in diameter and may be considered to be one candle power. Darken the room; the only light should be from the candle and the lamp to be measured. Move lamp *D* until a position is found where the transparent paper in the screen appears just as bright on one side as on the other. Measure the distance from *A* to *S* and from *S* to *D*.

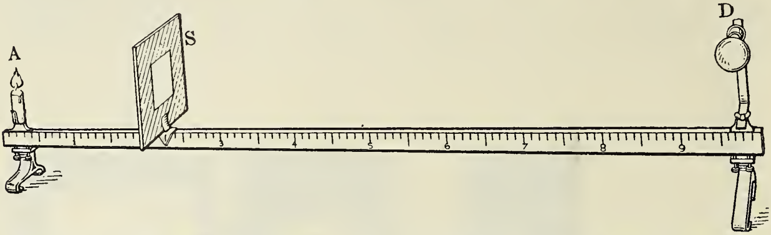


FIG. 235. The drawing shows how the candle power of lamp *D* can be measured.

What is the ratio of the distance of the screen from the lamp to the distance of the screen from the candle? What is the square of this ratio? How much stronger is the lamp than the candle? Since the candle is one candle power, what is the candle power of the lamp?

Does light travel in straight lines? Notice the lines (Fig. 234) drawn from the source of light through the opening in one cardboard to the other cardboard. These lines represent light rays. Are they straight or curved lines? Do you understand now why you cannot see around the corner of a building?

Experiment 105. To show that light travels in straight lines. In a darkened room set up apparatus as shown in Figure 236. *B* is a cardboard about a foot square with a small round hole in the center. *C* is a piece of unruled glazed paper.

With a few drops of oil, grease the center of the glazed paper so that the image of the candle can be seen from either side. Place the cardboard in an upright position about a foot from the candle. Place the greased paper close to, and parallel with, the cardboard. Move the greased paper slowly away from the cardboard and watch the center of the greased area. What do you see? In what position is it?

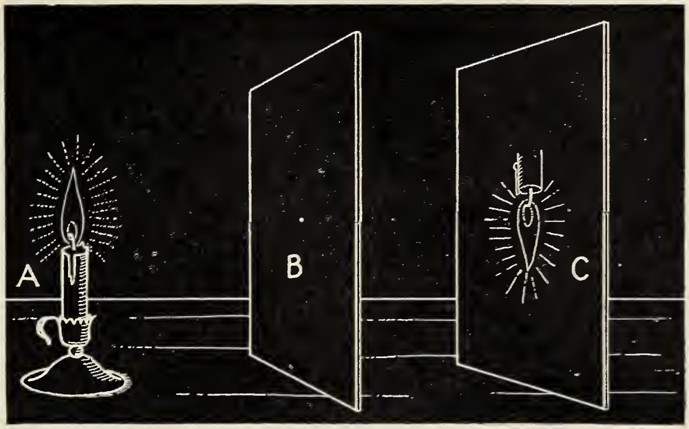


FIG. 236. How can you tell from this diagram that light travels in straight lines?

Does this experiment show that when a ray of light passes through a very small opening it travels in a straight line? If you extend a straight line drawn from the tip of the candle flame to the opening *B*, it will reach to the tip of the image of the candle. Any other straight line drawn from any other point in *A* through *B* would fall upon the corresponding point in the image of the candle.

You will notice, too, that the image of the candle is upside down (inverted). The image is inverted because light travels in straight lines.

A camera that forms images in this way is called a pinhole camera.

Special problem. To show how an image is formed in a box camera. Remove the back of a box camera and also the mechanism that holds the film. Set the shutter for a time exposure and open it. Focus the camera on a house or tree through the window. Now place a piece of oiled paper across the open back end of the camera. What do you see on the oiled paper? Is the image right-side up? Does the box camera produce a more distinct image than the pinhole camera? The purpose of the lens in a camera is explained on page 413.

What causes a shadow? Around the lighted area on the cardboard in Experiment 103, there was, of course, a shadow. Reread what was said about shadows on page 177. What causes night on the earth? A shadow is cast by any substance, such as wood, iron, or stone, through which light cannot pass; such a substance is called *opaque.*

A substance, like frosted glass, that permits part of the light that falls upon it to pass through but not enough so that an object can be seen clearly through it, is called *translucent.* Stained and frosted glass, oiled paper, and the thin porcelain used for lamp globes are translucent.

A substance such as window glass, that permits light to pass through it so readily that an object can be seen through it clearly, is said to be *transparent.* Name other transparent substances.

Experiment 106. To show the different parts of a shadow. Place an opaque cylinder about two inches in diameter on a table in a darkened room (Fig. 237). Place two lighted candles about six inches away from the cylinder in the position shown in the figure, making the distance between the candles equal to the diameter of the cylinder. Is there any space on the side of the cylinder opposite the candles that receives light from one candle but not from the other? How is this lighter shadow labeled in the figure?

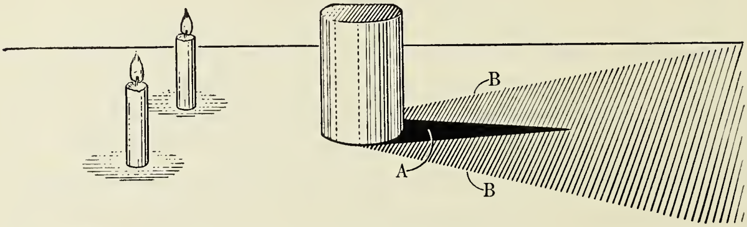


FIG. 237. If only one candle is used, will there be a lighter and a darker part to the shadow? Why?

The dark part of the shadow, A, cast by the cylinder does not receive light from either candle; it is called the *umbra.* The lighter part of the shadow, B, that receives light from one or the other candle is called the *penumbra.* From your study of the eclipse of the sun (page 177), can you tell what part of the moon's shadow causes a partial eclipse of the sun? A total eclipse?

PROBLEM: HOW IS ARTIFICIAL LIGHT PRODUCED AND HOW IS IT USED IN OUR EVERYDAY LIFE?

The uses of artificial light. Artificial light is used more and more as civilization advances. Even though all known provision is made for sunlight to enter the huge office buildings of today, many persons who work in them must spend their entire day in artificial light. In many apartment houses artificial light is needed even in the daytime. Even the people who live and work in buildings adequately supplied with sunlight must spend their evening hours in artificial light. Tennis, baseball, football, and even golf are played at night in artificial light. You can see how necessary it is to provide the most satisfactory artificial light and to select the most efficient lighting fixtures.

Experiment 107. To show how artificial light is produced. Hold a piece of wire in a flame. Notice that the wire becomes first warm, then hot, then red hot, and finally white hot.

The light from a white hot substance is called artificial light because it does not come directly from the sun. Does all artificial light come from the sun indirectly? Explain. Man has devised many ways of producing artificial light, but in every one the light produced is the result of heating matter until it glows, that is, becomes *incandescent*.

Light a Bunsen burner and open as wide as you can the holes at the base to permit the greatest amount of air possible to flow up through the burner. What color is the flame? When there is sufficient air, the flame is blue because all of the little particles of carbon in the flame unite immediately with the oxygen and burn.

With the thumb and forefinger close the holes. What color is the flame now? Does it produce more or less light than the blue flame? Closing the holes cuts off air from the tube of the burner, and since the carbon particles are not burned at once, they are heated sufficiently to produce light.

Candles as a source of light. It is quite possible that the great-grandparents of some of you lighted their homes with candles. Indeed, even lighthouses at one time had to depend upon candles for their light; as late as 1811 the famous Eddystone Light thirteen miles from Plymouth Harbor, England, was produced by twenty-four wax candles. We still use candles for certain scientific experiments and in emergencies when electric lights go out. Candles are also used for decorative purposes because their soft yellow light is pleasing to the eye.

Experiment 108. To make candles. Dip a string into a test tube containing melted paraffin. Withdraw it and, after permitting it to cool slightly, dip it again in the paraffin. Repeat the process a number of times and note the result. Will this homemade candle burn?

The heat of the flame melts the paraffin and the melted paraffin is drawn up the wick by capillary attraction. At the end of the wick the heat produced by the burning string is intense enough to vaporize the paraffin; it is this vaporized paraffin which burns.

Kerosene lamps as a source of light. Previous to the introduction of petroleum in 1859, lighting materials, whether used in candles or in oil lamps (Fig. 238), were obtained from the fats and oils of plants and animals. The practical use of petroleum in lamps dates from the discovery of a refining process by which kerosene is obtained from it.

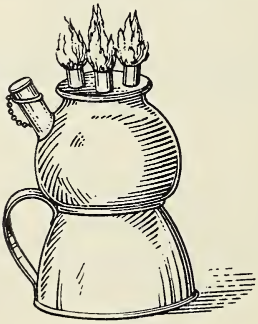


FIG. 238. A whale oil lamp. Why was whaling an important industry before the discovery of petroleum?

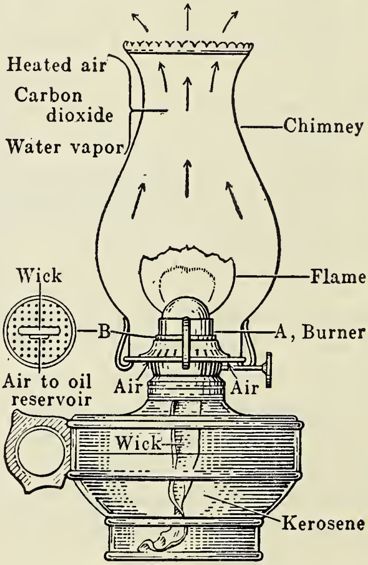


FIG. 239. A kerosene lamp. Explain how carbon dioxide and water vapor are formed by the burning kerosene. *B*, a section through the burner.

To burn kerosene in a lamp successfully it is necessary to supply the flame with enough air to keep it from smoking. Kerosene, as you have learned, is a hydrocarbon—that is, it is composed of carbon and hydrogen. When kerosene burns, oxygen from air unites with carbon in the kerosene to form carbon dioxide and with the hydrogen in the kerosene to form water (Fig. 239).

Another type of kerosene lamp is the central draft lamp. The wick in this lamp is in the shape of a hollow cylinder. The flame is supplied with oxygen from the air which rises through the center of the wick as well as from the air which comes in through holes at the bottom of the burner. Still another type of kerosene lamp is operated by means of compressed air; by the use of a "mantle" this lamp produces a very bright light.

How is gas used for lighting? Both natural and artificial gas are used for lighting. In cities not conveniently located near a natural gas supply, artificial gas is manufactured from coal. Artificial gas is stored in tanks under pressure (Fig. 240). From these tanks it forces its way through pipes to homes, factories, and the like, where it is used for lighting and heating.

In 1885 Welsbach placed his invention, the Welsbach mantle, upon the market (Fig. 241). The invention came about in a rather unlooked for way; while experimenting, Welsbach set fire to pieces of cotton soaked with solutions obtained from two rather rare metals, thorium and cerium. Even after the cotton was burned, the ash kept the shape and size of the pieces of cotton and glowed with an intense white light when he held it in a gas flame.

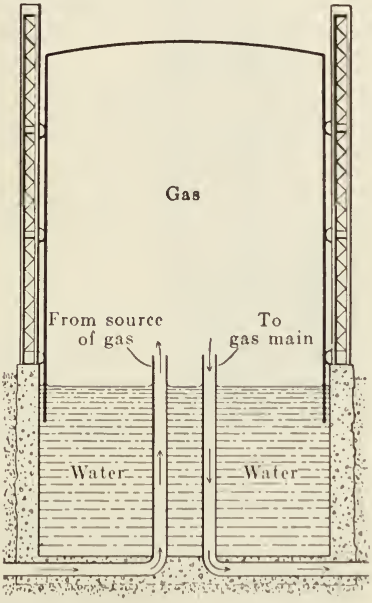
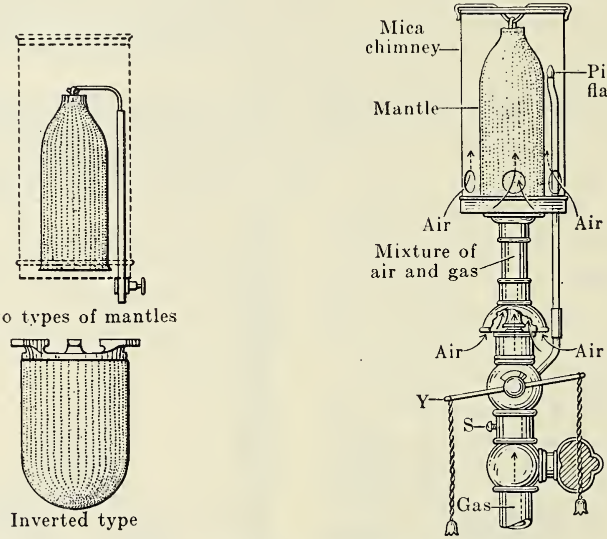


Fig. 240. A commercial gas tank in which gas is stored over water.

The brilliant light given off by this ash led to the making of thimble shaped mantles of cotton or artificial silk saturated with solutions containing thorium and cerium. One of these is placed over a gas burner, which is then so adjusted that the carbon in the gas is completely oxidized. The intense heat from the blue flame heats the mantle to incandescence, giving a much brighter light than could be obtained with the blue flame. Of course the cotton or silk burns when the mantle is first used, but the ash retains the original shape of the mantle. The modern gas lamp is a modified Bunsen burner equipped with a Welsbach mantle and a device by means of which the proper relative amounts of gas and air are burned.


Two types of mantles

Inverted type

Fig. 241. In the gas lighting fixture shown at the right, a pilot flame is always burning, the amount of gas fed to it being regulated by turning the screw at *S*. By means of lever *Y* the flow of gas that furnishes the main light is regulated.

Electricity as a source of light. Kerosene and gas lamps are rapidly being replaced by electric lamps. This is true not only in cities, but also in rural districts where electric current is supplied from central stations or from storage batteries which are charged by small power plants. The electric lamp has a number of advantages over other lamps used for lighting purposes: (1) it is cleaner; (2) it does not take oxygen from the air; (3) it is very easily operated; (4) it is odorless; (5) it does not give off much heat.

Experiment 109. To discover the structure of an electric light bulb. Obtain a "burned out" bulb and heat the brass cap over a Bunsen flame until the materials under the cap begin to soften. With a pair of pliers twist off the cap. Examine the paste inside the cap. What two purposes does the cap serve?

Now heat slightly the end of the bulb that was next to the cap and pour cold water on it to crack the glass. By tapping the cracked glass gently with a screw driver the entire contents will fall out of the neck of the bulb.

Note the fine wires and examine their connections. Hold the wires in the flame with the aid of pliers and notice how soon they become incandescent. Notice, also, that if they are held in the flame for a time, they are burned. Why did the wires not burn when the bulb was in use?

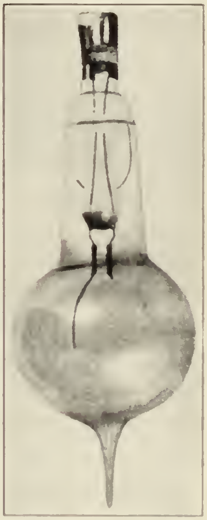


FIG. 242. How does this electric lamp differ from the ones in use today?

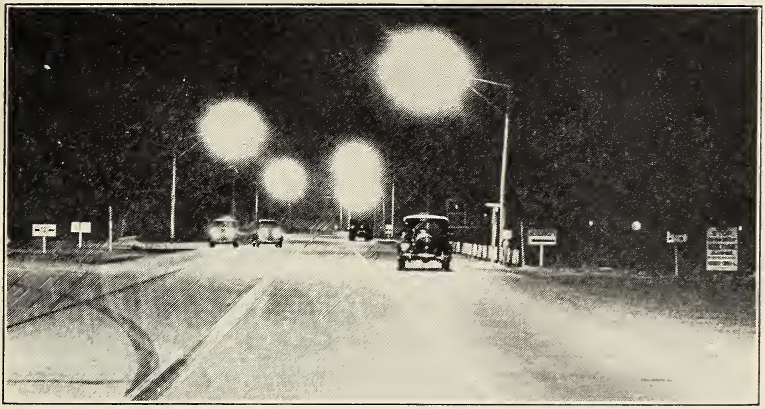
When the bulb was lighted, the wires were heated because they offered resistance to the electric current. As the current was forced through the wire, some of its electric energy was changed into heat energy and the heat energy was changed into light energy. In order to be efficient producers of light, wires must offer enough resistance to the passage of a current to cause them to become incandescent.

The invention of the incandescent lamp. The incandescent lamp as first used in our homes was invented by Thomas Edison in 1879. J. W. Swan, an English scientist, was working on a similar lamp at about the same time. It was already known that a current of electricity passing through a fine wire would produce enough heat to make the wire incandescent. However, an incandescent wire in air soon becomes oxidized and breaks. Of course Edison knew that for a practical incandescent lamp this fine wire would have to be made of material that would not easily melt or vaporize, and that it would have to be heated away from air. He experimented with carbonized filaments (charred threads) of cotton and bamboo. Finally he succeeded in fitting a charred bamboo filament into a glass container from which a large part of the air had been exhausted. When he passed an electric current through the filament, light was produced; this rather crude apparatus was the first incandescent lamp (Fig. 242).

Experiments with the carbon filament continued until about 1894; during this time filaments were greatly improved.

The tungsten lamp. In modern electric lamps a fine filament drawn from the metal tungsten is used. Such a lamp has been found by experiment to produce a much more efficient light than a lamp with a carbon filament. It requires only about one-third as much electric power to give the same amount of light. Tungsten melts at about 3400° C. and it can be drawn into very fine wire (0.3 mm. in diameter). As a result it can be heated without melting to such a high temperature that a dazzling white light almost like sunlight is produced. Therefore it is an ideal material for filaments. If the tungsten filament is used in a vacuum globe, however, tiny particles of the tungsten will be vaporized and deposited on the sides of the globe, thus making it less transparent. To prevent the vaporization of the filament, the globe is often filled with gas that does not unite with other substances, such as nitrogen or argon. Either of these gases in an electric lamp will slow down the vaporization of the tungsten, thus keeping the glass clear for a long time. These lamps are known as gas filled lamps.

Neon lamps. Neon lamps represent a different type of gas-filled lamp which has many commercial uses. To make a neon lamp, a glass tube is used. In each end of the tube an electrical terminal is sealed. The air is exhausted from the tube, a very small amount of neon or other gas is admitted, and then the tube is sealed. Light is produced as electricity passes from one terminal to the other through the rarefied gas. Light produced by neon gas is orange red. Other colors are produced by the use



Courtesy General Electric Co.

FIG. 243. U. S. Highway Route 20 at Michigan City, Ind., illuminated with sodium vapor lamps.

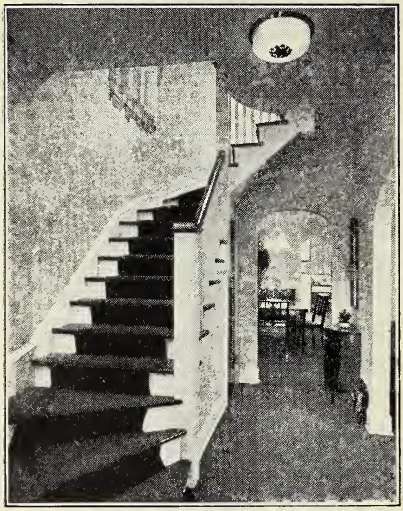
of helium, argon, mercury vapor, and other gases. Sometimes colored glass and a combination of gases are used to produce a certain color. Neon lamps can be made several feet long and in many different shapes. Consequently, they lend themselves readily to advertising. Both night and day lighted neon signs made in forms of letters, words, or special designs may be seen. Landing fields for airplanes are lighted by neon lamps. The beacon lights which guide airplanes through the night also have these lamps.

Sodium vapor lamps are used for highway illumination. Automobile driving at night is much safer on well-lighted highways.

Why are lighting fixtures used? Artificial light has been called by lighting engineers the "raw product," and "illumination" the finished product. From this point of view lighting fixtures are used to change the raw product, light, into the finished product, illumination. Let us find out how lighting fixtures are used to bring about this change. Lighting fixtures in our homes may be divided into three classes according to the kind of illumination they furnish; (1) direct, (2) indirect, and (3) semi-direct.

Direct lighting permits light to pass directly from its source to the object to be illuminated. A serious objection to direct lighting is that light may shine directly in the eyes of persons in the room. The light from an electric lamp is so bright that, if it shines directly in a person's eyes, they are apt to be injured. To protect the eyes from direct lighting, shades are placed over lamps. A dark shade should be avoided, however, because it does not permit enough light to pass through it, and it may produce shadows. Fixtures in which the lamp is enclosed in a translucent globe are satisfactory because the light is scattered (diffused) throughout a room in every direction. This diffused light is much more restful to the eye than a direct light.

In indirect lighting, light is reflected from the bowl of the lamp to the ceiling and walls, which, in turn, reflect and diffuse the light throughout the room. This kind of illumination prevents glare and dark shadows, but it is very wasteful of light (see page 407). When it is used, the ceiling and upper part of the walls should be light in color, and the lamp bowl should be kept free from dirt so as to insure the greatest reflection possible.

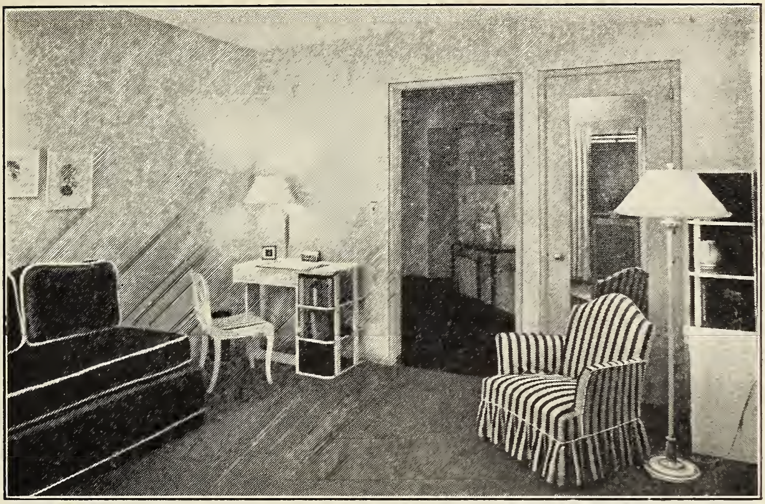


Courtesy General Electric Co.

FIG. 244. Well-lighted stairways aid greatly in preventing accidents in the home.

The semi-direct system combines the most desirable features of both direct and indirect lighting. The translucent bowl, instead of reflecting all the light to the ceiling, reflects part of it upward and diffuses the rest of it downward. The light that passes downward and through the translucent bowl is diffused sufficiently to prevent glare, and light reflected from the ceiling tends to brighten any shadows that may be formed by the diffused light.

Decorative floor and table lamps contribute to the beauty of the home; the lighting efficiency of such lamps should be considered, however, as well as their decorative features. Since these



Courtesy General Electric Co.

FIG. 245. A well-lighted room. Explain what methods of lighting are used.

lamps are generally so placed that they are in the direct path of vision, the shades should be such that they prevent glare; but they should still permit sufficient light to pass through to bring out their artistic designs. These portable lamps can be arranged so as to light effectively those parts of the room where light is most needed. Certain features of the semi-direct system can be made to apply to these lamps if they are so constructed as to permit part of their light to reach the ceiling, from which it is reflected to all parts of the room, thus producing a well diffused and pleasing light.

Glare from automobile headlights. One cause of accidents in automobile driving at night is glare from the headlights of approaching automobiles. In order to make night driving safer, automobile headlights have been improved to give better illumination on the road. This improvement has consisted largely in increasing the intensity of the light. At night when a driver meets an approaching automobile with very bright lights, it is very difficult for him to see the road. You may have had this experience when driving or riding in an automobile. However, it is possible to have excellent illumination and at the same time avoid glare. Glare can be avoided by dimming devices or by devices which either tilt the beam of light downward on the road, or shift it to one side. In order to make night driving safer, many cities have passed ordinances, and states have passed laws to compel drivers to dim their headlights when approaching other motorists. Recent experiments indicate that we may have lights which avoid glare and at the same time give satisfactory illumination on the road. Improvements of this kind will aid greatly in promoting safety.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

artificial light
candle power
direct lighting
filament
foot candle
illumination
incandescent
indirect lighting
intensity
opaque
paraffin
penumbra
semi-direct lighting
shadow
translucent
transparent
tungsten
umbra

Write the number of each item on your paper and after it the word that completes the statement.

1. A Bunsen flame becomes luminous because of particles of glowing ________.
2. The unit for measuring the intensity of light is the ________.
3. The intensity of light from a given source varies inversely as the ________ of the distance.
4. A pupil who sits twice as far from a lamp as another pupil receives ________ as much light.
5. The part of a shadow that does not receive any light from a given source or sources is called the ________.
6. The part of a shadow that receives some light is called the ________.
7. A burning kerosene lamp takes ________ from the air.
8. The American who invented the incandescent lamp was ________.

Which item in each of the following lists does not belong with the others?

9. transparent; umbra; opaque; shadow; penumbra.
10. stained glass; muddy water; translucent substance; pure water; frosted globe.

CHAPTER XXII

HOW DOES LIGHT GIVE US COLOR AND PRODUCE THE SENSATION OF SIGHT?

Do you know:

That it takes light from the sun about eight minutes to reach us? How many miles light travels each second? That the moon has no light of its own? That you see only objects which reflect light?

That rays of light can be bent? What you must do to spear a fish under water? Why a lens is used in a camera? That certain chemicals are changed by light? What causes a rainbow? Why a black suit is warmer in sunlight than a light suit of the same material? That a dress is red because it reflects only red rays of light to the eye? That the eye contains a lens? That a membrane of the eye serves about the same purpose as the plate of a camera?

PROBLEM: WHAT IS LIGHT, AND HOW IS IT TRANSMITTED?

The question of what light is and how it is transmitted is one that science has not yet answered definitely. Newton thought light to be composed of very small particles (*corpuscles*) streaming off from an incandescent substance. Huygens, a Dutch astronomer who lived at the same time, said that light consists of waves which produce the sensation of sight much as sound waves produce the sensation of hearing. You know that waves are always transmitted by a medium, the parts of which vibrate. Since light comes to us from the sun and the atmosphere does not fill all of the space between the earth and the sun, Huygens thought he was compelled to assume the presence of a medium in this space. This medium, which he assumed filled all space, even the spaces between the molecules of liquids and solids, he called *ether*.

Neither the corpuscular theory of Newton nor the wave theory of Huygens explains all of the facts known about light. New theories are advanced from time to time and scientists are at work testing them. So far, the wave theory seems to explain more of the facts than any other.

Light waves are of different lengths. Just as there are waves in the air which cannot be heard, so there are light waves which cannot be seen, because they are either too long or too short to produce the sensation of sight. The eye is able to interpret as light only those light waves between .0004 mm. and .0007 mm. in length. Do you realize how short these light waves are? It would take about 1000 of them to equal the diameter of a hair.

Light waves shorter than .0004 mm. are too short to affect the eye as light. These shorter waves are known as *ultra-violet rays.* They are thought to assist greatly in maintaining sound health. They cause our bodies to tan when exposed to the sun. Still shorter waves are *X-rays* used by physicians, dentists, and scientists, to obtain "pictures" of interior parts of the human body, and other opaque substances (Fig. 246).

The complete spectrum. The waves of the complete spectrum (Fig. 246) that concern us most are: (*a*) radio waves, which vary in length from a few feet to several miles; (*b*) heat waves, very much shorter than the shortest radio wave but too long to produce the sensation of sight; (*c*) light waves, which vary in length from .0004 mm. to .0007 mm.; and (*d*) ultra-violet and X-rays, shorter than the waves which produce light.

The speed of light. The speed of light waves is so great that for many years light was believed to travel instantly from one place to another. In 1676, however, the Dutch astronomer Roemer found that it took time for light to travel from one place to another, thus disproving the older belief.

The story of Roemer's determination of the velocity of light is an interesting one. He was making observations of the revolutions of the moons of Jupiter. One of these moons revolves about Jupiter once every 42½ hours, which means, of course, that it is eclipsed by Jupiter about every 42½ hours. An astronomer named Cassini had prepared charts which showed for several years ahead the exact minute when these eclipses would occur. Imagine Roemer's surprise to discover that the time when the eclipses occurred did not agree with the time in Cassini's charts.

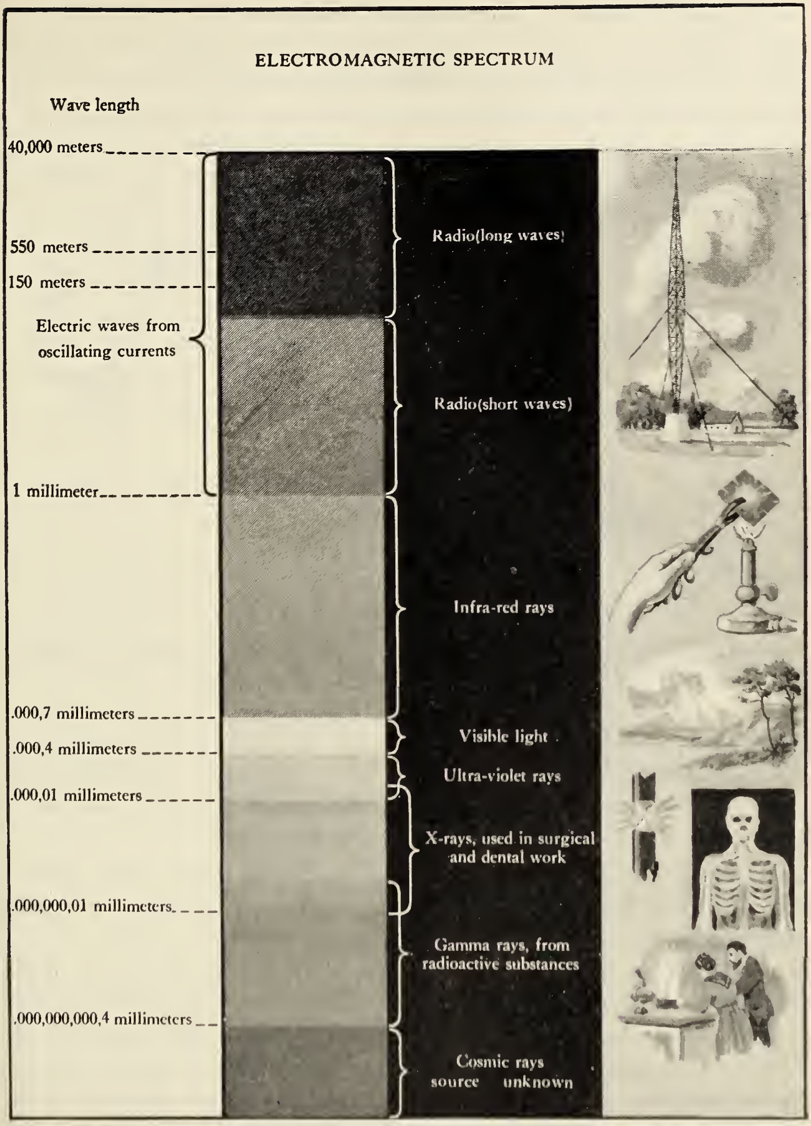


FIG. 246. Visible light waves, as you see, make up a very small part of the electromagnetic spectrum. Of course, this drawing is not made to scale.

Figure 247 will help you to understand how Roemer explained this difference. At one time of the year the earth and Jupiter are on the same side of the sun in the positions *E* and *J*; just about six months later they are on the opposite sides of the sun in positions *E′* and *J′*. Roemer noticed that as the earth traveled from position *E* to position *E′* the interval between eclipses increased; but as it traveled from position *E′* back to position *E* again, the interval between eclipses decreased. The difference between the longest and shortest interval he found to be about 16½ minutes.

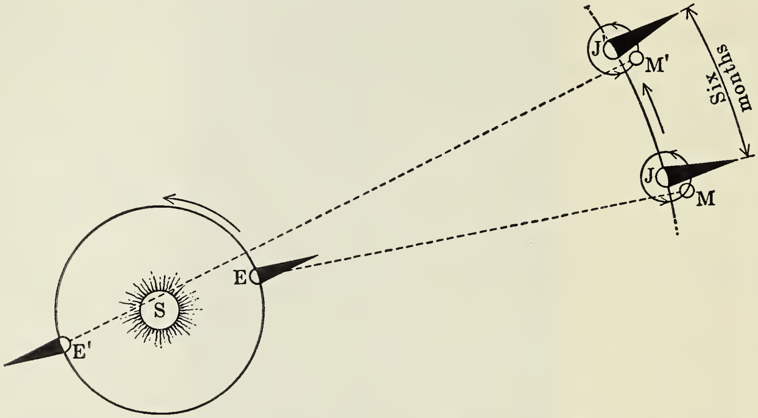


FIG. 247. Point out the position of the sun, the earth, and Jupiter during Roemer's first observation; six months later.

Roemer explained the difference as being due to the longer distance the light from the moon in position *M′* had to travel to reach the earth. The distance from the moon at *M′* to the earth at *E′* is greater than the distance from the moon at *M* to the earth at *E* by the diameter of the earth's orbit—186,000,000 miles. If it takes light about 16½ minutes (1000 seconds) to travel this distance, then light must travel at about 186,000 miles per second. Since the time of Roemer other scientists have performed experiments for the purpose of measuring more accurately the speed of light. One scientist, Professor Michelson, devoted years to this work. In 1926, he announced that his experiments at Mt. Wilson observatory indicated the speed of light to be 186,284 miles per second. For his very careful work Professor Michelson is greatly honored by other scientists. The final checking of this result, which was interrupted by Professor Michelson's death in 1931, was completed by his assistants.

When you consider the great speed at which light waves travel and the tiny length of a light wave, you know that a great many light waves must strike the eye each second. It has been calculated that when we see red light, no fewer than four hundred million million waves enter the eye in a second. The number of light waves that pass a given point in one second is called the *frequency* of light.

Special problem. How long does it take light to travel from the sun to the earth?

What makes it possible for us to see an object? We learned in our study of sound that when sound waves made by the voice travel through air until they come into contact with a building or a mountain, they rebound (somewhat as a rubber ball rebounds from the floor) and come back to their source as an echo. Similarly a light wave striking an opaque object, rebounds and travels at the same speed as light coming directly from an incandescent body. This rebound of light waves is known as *reflection.*

If it were not for the reflection of light, we would be able to see incandescent bodies only. We can see a chair, for instance, because light from the sun or from an artificial source strikes the chair and is then reflected from the chair to our eyes. We could not see the moon if it were not for the sunlight that is reflected from its surface. Usually reflected light is soft and pleasing to the eyes. Owing to the reflection of light, the brightness of light in our homes is determined partly by the color of the wall paper, the woodwork, and the furnishings. If the walls and furnishings of a room are white, a large part of the light striking them is reflected, thus making the room lighter than it would be without the reflected light. If the walls, woodwork, and furnishings are dark, a large part of the light striking them is absorbed thus making the room darker than it would be if light were not absorbed. For the most approved illumination a high gloss should be avoided in decorating the walls and ceiling of a room because a gloss produces glare.

PER CENT OF LIGHT REFLECTED BY DIFFERENT COLORS USED IN FINISHING WALLS AND CEILINGS

Color	*Per Cent*	*Color*	*Per Cent*
White	80	Buff	59
Ivory White	76	Pink	51
Ivory	72	Tan	37
Pearl Grey	70	Sky Blue	37
Primrose	67	Cardinal Red	31
Light Green	67	Olive Green	14

Mirrors are excellent reflectors of light. In fact, when rays of light reflected from a person or object strike a mirror, they are reflected so perfectly that an accurate image of the person or object can be seen in the mirror. Sometimes one's image is so perfect that he scarcely realizes the presence of a mirror.

A mirror is nothing more than a flat piece of glass covered at the back with silver or with a flat polished piece of metal. Formerly most mirrors were made by the long and tedious process of coating the glass with an alloy of mercury and tin. Nowadays a coating of silver is deposited on glass from a silver nitrate solution and this deposit painted with a dark colored paint.

Experiment 110. To study reflection in a mirror. Stand a mirror on your desk. Fasten a pin in front of the mirror. Observe the image of the pin. Where does it appear to be? How far is the pin in front of the mirror? How far behind the mirror does the image appear to be? Try to look from such a position that the pin and its image appear to be one and the same thing, i.e., to coincide. Notice that the pin and its image appear to coincide only when your eye, the pin, and the image are in a straight line.

Draw a line AB (Fig. 248) on a piece of paper. On this line stand a mirror MN. Fasten a pin, P_1, at point C; and a second pin, P_2, a short distance from the mirror and a little to the right of the first pin. The image of P_2 is indicated on the diagram by P'_2. With your eye close to the paper, place a third pin, P_3, so that this pin, pin P_1, and the image P'_2 appear to be in a straight line. Remove the mirror and draw the line from P_1 to P_2 (line CF) and the line from P_1 to P_3 (line CE). Now draw the line CD perpendicular to AB. With a protractor measure angles r and i. Are they equal?

Angle i, made by a line representing the path of a ray of light from pin P_2 to the mirror and the line perpendicular to the mirror, is called the *angle of incidence.* Angle r, made by a line representing the path of the ray of light reflected from the mirror and the line perpendicular to the mirror, is called the *angle of reflection.* The angle of incidence is equal to the angle of reflection.

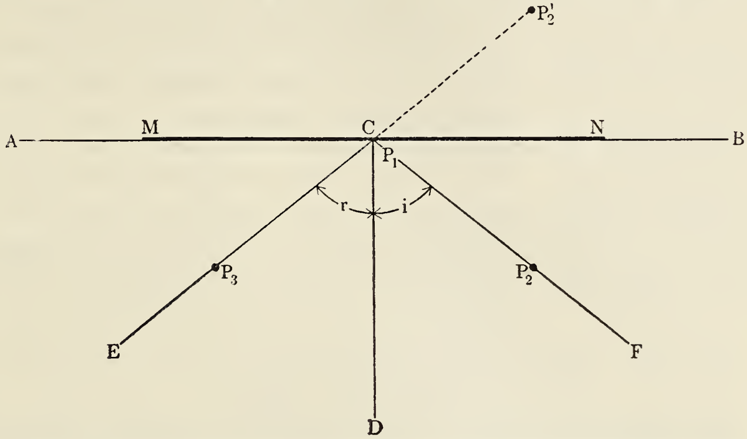


FIG. 248. How does the angle of incidence compare with the angle of reflection?

Figure 249 also shows the apparent position of an object when seen in a mirror.

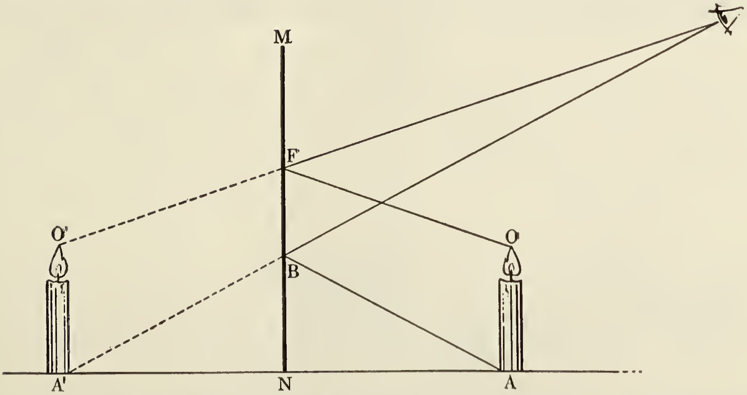


FIG. 249. Where does the candle OA appear to be when a person standing behind it looks into the mirror, MN? How does the distance AN compare with the distance $A'N$? Measure them.

Diffused or scattered light. The surface of most objects is rough in comparison with the surface of a mirror; consequently the light reflected from them is scattered in all directions. Why? This scattering of light is known as *diffusion.* Figure 250 illustrates the diffusion of light when reflected from a rough surface. Sometimes bright sunlight strikes snow in such a way that little diffusion takes place. As a result reflected light produces a glare that causes discomfort to the eyes. During the day most of the light coming into our homes is sunlight which has been diffused by particles in the atmosphere, trees, buildings, and other objects.

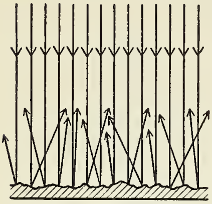


FIG. 250. Diffusion of light. What happens to light when it is diffused?

PROBLEM: HOW IS THE TRANSMISSION OF LIGHT AFFECTED BY TRANSPARENT BODIES?

Can light rays be bent? You have noticed, no doubt, that the handle of a spoon seems to be bent when the spoon is placed in a glass of water. You may have heard, too, that it is difficult for a beginner to spear a fish. The experiment that follows will help you to explain these phenomena.

Experiment 111. To show the bending of light rays. Place a coin in an opaque cup. Move away from the cup until you reach the place where the coin is just out of your sight (Fig. 251). Keep your eyes fixed on the spot near which you last saw the coin while some one fills the cup with water, taking care not to move the coin. Is the coin visible now? Has the coin changed its position?

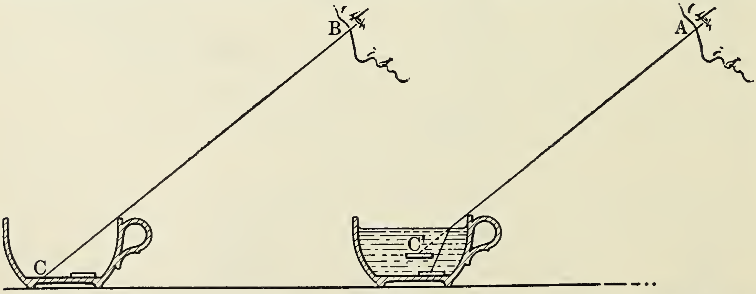


FIG. 251. Refraction of light. What happens when light passes from water to air? Air to water?

When the cup was empty, the light rays traveled from the cup to the eye along line BC; but when the cup was filled with water, the light rays reflected from the coin traveled in a straight line to the surface of the water, where they were bent toward the eyes of the observer at A, thus making the coin appear to be on a straight line running from the eye at A to C', and therefore visible.

From what you have just learned, if you were trying to spear a fish in water, would you aim at the fish where it appears to be? If not, where would you aim?

This bending of rays of light as they pass from one transparent medium to another of different density is known as *refraction.* Light is refracted as it passes from air to water, from water to air, from glass to water, or from water to glass. This bending of light takes place only when the rays of light meet the surface of the transparent medium at an angle other than a right angle. It is this behavior of light which makes it possible to take pictures with a camera; to study the heavenly bodies with a telescope and tiny bacteria with a microscope; to prevent eye strain and even blindness by the use of glasses. Indeed, the human eye itself is so constructed that light rays are bent in passing through it.

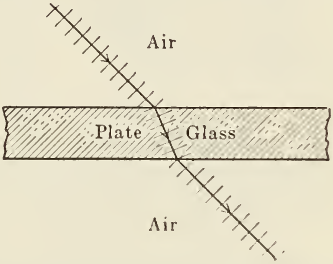


FIG. 252. Is the direction of a ray of light changed when it passes from air into plate glass? When it passes from plate glass into air?

What causes the refraction of light? The refraction of a ray of light is due to the change in the speed of light waves as they pass from one transparent medium into another. Figure 252 represents the way a ray of light is bent as it passes from the air through plate glass and into the air again. Light travels more slowly in glass than in air. As a light ray strikes a glass obliquely, the lower part of the ray enters the glass first and its speed is slowed down. At the same time the speed of the upper part of the ray is unchanged. Consequently the upper part of the ray gets ahead of the lower part, and thus the ray of light is bent as shown in the figure. Somewhat the same kind of phenomenon occurs when you stumble; that is, your head moves faster than your feet, and your body is bent forward.

As the ray leaves the glass, the lower part which reaches the air first immediately increases its speed, while the upper part still in the glass continues at a speed unchanged. Thus it is bent again, but this time in the opposite direction.

If the ray of light is perpendicular to the surface of the glass, it will not be bent in either direction; its speed will be changed, however, decreasing as it enters the glass from the air and increasing as it leaves the glass. Do all the light rays that are perpendicular to a glass surface enter the glass? Explain.

Types of lenses. A transparent body (usually glass) used to refract light rays is called a *lens*. Lenses are used in cameras, microscopes, telescopes, eye glasses, field and opera glasses, stereopticons, and other optical instruments.

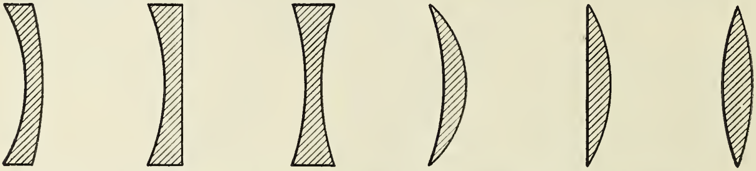


FIG. 253. Which of these lenses are convex? Which concave?

A lens has two curved surfaces, or one curved and one flat surface. The curved surfaces are usually spherical and may have any of the forms shown in Figure 253. There are two general classes of lenses: *convex* lenses, which are thicker in the middle than at the edge; and *concave* lenses, which are thicker at the edge than in the middle. A light ray passing through a lens is always bent toward the thickest part of the lens.

Experiment 112. To show how light rays are refracted by a convex lens. Hold a convex lens in direct sunlight coming through a window. Scatter some crayon dust in the air near the lens, and notice that the light rays are refracted until they meet (converge) at one point. The point at which the light rays converge is known as the *focus*. Hold a piece of tissue paper at this point. What happens? Explain.

Look at this page through a hand lens. Do the letters appear changed?

Experiment 113. To form an image with a convex lens. Draw the shade on every window in the room except one. Hold a convex lens near the wall opposite the window whose shade was not drawn. Move the lens toward the window and then away from it, until you have found a point where the clearest image of the window is thrown on the wall. In what position is the image? The light rays from the window sash are refracted by the lens so that they converge and produce an image on the wall. Measure the distance from the lens to the image on the wall. The distance from a lens to the image formed by it is called the *focal length* of the lens.

A magnifying glass. A simple magnifying glass is nothing more than a convex lens. In Figure 254 rays of light from the knife, *MN*, are refracted by the lens and brought to a focus in the eye, *A*. The lines of sight *AB* and *AC*, that appear to be projected from the eye are straight. The image, *M'N'*, of the object, *MN*, appears to be farther away from the lens than the object itself, because the lines of sight, *AB* and *AC*, get farther and farther apart and thus the image, *M'N'*, of the object, *MN*, appears larger than the object itself.

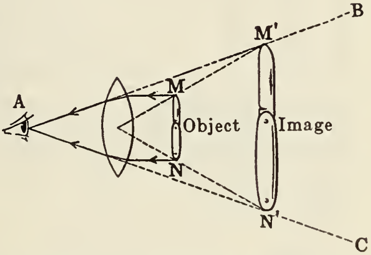


FIG. 254. A magnifying glass. Trace the rays of light from the object to the eye and then to the object which the eye appears to see.

Compound microscopes, telescopes, and field glasses are combinations of lenses that make tiny objects seem larger, or that make distant objects seem nearer.

The camera. This is another familiar device in which a lens is used. It consists of a black box so constructed that light rays can enter only through the shutter *S* (Fig. 255). From the shutter they pass through a lens and form an inverted image of objects on ground glass or sensitive plate or film attached to the rear inside of the box. The picture is produced by the chemical action of the light on the plate or film.

Some substances are affected more by light than others. Compounds of silver with either iodine or bromine are very sensitive to light. They are used extensively in making plates or films used to take pictures. A thin coating of gelatine that contains compounds of silver is part of a film or plate.

Taking a picture. When a picture is to be taken, the person or object to be photographed is brought within the range of the lens. The shutter of the camera is snapped open to admit the light. In taking outdoor pictures the length of time that the shutter should remain open depends upon the time of day and the clearness of the sky. In a photograph studio, however, lighting conditions are so controlled that picture taking is independent of outdoor conditions. The time during which a film or plate is exposed to light by a photographer may be $\frac{1}{25}$ or $\frac{1}{50}$ of a second. The stronger the light entering the camera, the shorter the time required for the exposure. When a camera has been focused upon an object or scene and the shutter has been quickly opened and closed (snapped), the first step in the process of making a picture is completed.

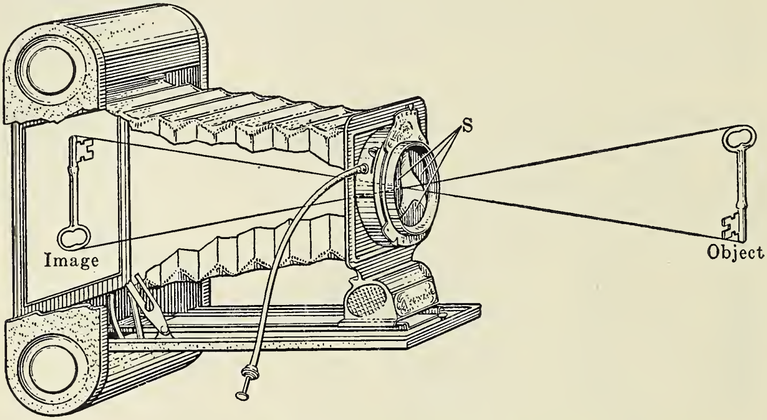


FIG. 255. In a camera like this, the shutter at *S* is snapped open when a photograph is to be taken, allowing light to strike the lens (directly behind the shutter) which focuses light from the object upon the film or plate as shown.

If we were to look at a film that has been used, we would not be able to detect any change, but nevertheless light has produced a chemical change in the film. Let us suppose, for instance, that the subject which we are to photograph is a boy wearing a dark coat and a white shirt. More light will be reflected from his white shirt than from his dark coat, and consequently the part of the film receiving light from his shirt will be more affected than the part receiving light from his coat. This difference in effect can be seen when the film is treated with a solution made from chemicals called a *developer*. The developer causes a deposit of silver to be made on those parts of the film acted upon by the light. The part of the film that corresponds to the white shirt will receive a thicker deposit of silver than the part of the film which corresponds to the dark coat. The result is that the light portions of the boy photographed appear dark on the film, and the dark portions appear light. Therefore, the plate or film, which at this stage is called a *negative*, shows the boy in a light coat and a dark shirt.

The printing paper used to make a photograph also contains compounds of silver but these are not so sensitive to light as the silver compounds used to make a film. The printing paper is placed behind the negative and both are then exposed to light. The dark parts of the negative, i.e., where the thicker deposits of silver were made, do not permit much light to pass through to the printing paper; therefore behind these parts the print will be light. The lighter parts of the negative, i.e., where the thinner deposits of silver were made, will permit more light to pass through to the printing paper thus affecting the printing paper more, and, therefore, making those parts of the print appear darker. Consequently, the light and dark parts of the print are just the opposite of those on the negative. The print, then, shows light and dark shades as in the original subject.

Motion pictures. Films for motion pictures are very much like kodak films except in size. They are made in strips several hundred feet long and from three-fourths of an inch to an inch in width (Fig. 45).

The pictures are taken with a motion picture camera. In principle a motion picture camera is a modification of a kodak, with an attachment for moving the film as the picture is photographed. The film is wound on a reel and placed in the camera.

In taking a motion picture, the photographer by means of a crank or spring unwinds the film from one reel and re-winds it on another. As the film moves from one reel to another, it keeps stopping momentarily so that sixteen to twenty-four separate pictures are photographed in a second (Fig. 45). After a reel of film has been exposed, it is developed and prepared for the motion picture projector.

In the operation of a motion picture projector the film moves through the projector in front of a strong beam of light. Sixteen to twenty-four separate pictures are thrown on the screen each second, the light being shut off from the screen after each one. What appears to be a continuous moving picture on the screen is really a series of pictures, each separated from the other by a very short period of darkness.

A spectator viewing a motion picture on the screen sees sixteen to twenty-four separate pictures a second; each picture is slightly different from the picture that precedes it. Since the image of a picture does not fade immediately from the consciousness of the spectator, he retains the image of one picture until the next picture is flashed on the screen. Owing to this fact and also to the fact that each picture is slightly different from the one preceding it, the spectator looking at the series of pictures receives the sensation of moving objects on the screen. Moving pictures are combined with sound (page 62) to make up "sound movies."

PROBLEM: WHAT CAUSES A RAINBOW?

Experiment 114. To learn what happens when a ray of sunlight passes through a prism. Hold a glass prism in a ray of sunlight so that the refracted rays may be thrown upon a white screen at the opposite side of the room. Can you explain what causes the band of beautiful colors?

The solar spectrum. You learned at the beginning of this chapter that light waves are of different lengths, and that only light waves that are from .00041 to .00076 mm. in length produce the sensation of light. Physicists tell us that sunlight (white light) is made up not of waves of one length but of waves of different lengths. When these waves are separated one from the other, each wave produces its own color. These colors side by side are known as the *solar spectrum*. As we look at the colors shown in Experiment 114 we may distinguish seven, blending into each other in this order: violet, indigo, blue, green, yellow, orange, and red. We frequently refer to them as the colors of the rainbow.

Experiment 115. To show the refraction of light rays. Paste two narrow bands of colored paper, one violet and one red, on a black card and look at them through a glass prism. What do you notice about the violet band? The red band? How do you account for this? Are violet rays refracted more or less than red rays?

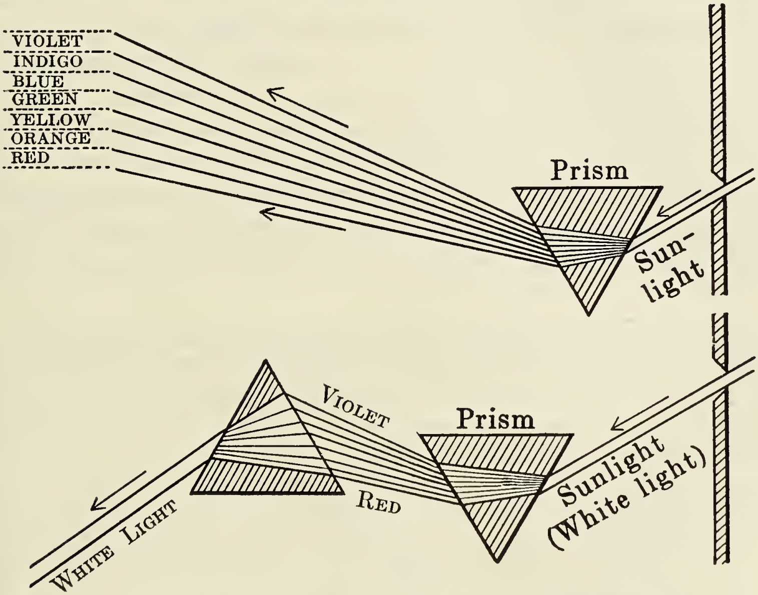


FIG. 256. In the upper diagram a ray of sunlight is shown passing through a prism. In the lower diagram a ray of sunlight passes through two prisms, one of which undoes the work of the other. Explain.

When white light is passed through a prism the waves that produce one color are refracted differently than the rays that produce another color. In fact, red rays are refracted the least, orange next, and so on through the colors of the solar spectrum with violet rays being refracted the most. This difference in the amount of refraction is what causes the arrangement of colors like that in Figure 256. Just as white light can be separated into seven bands of color by passing it through a prism, so the seven bands of color become white light again by passing them through a second prism (Fig. 256).

The lengths of the light waves that make up sunlight are:

Violet	.00041 mm.	Yellow	.00057 mm.
Indigo	.00043 mm.	Orange	.00062 mm.
Blue	.00047 mm.	Red	.00076 mm.
Green	.00052 mm.		

Which are the longest? The shortest?

The rainbow. It frequently happens, during a shower, that the sun shines on raindrops so as to produce a huge curved solar spectrum, known as a *rainbow.* As a ray of sunlight enters a raindrop it is refracted in much the same way as it was by the prism. It is refracted as it passes from the air into the raindrop, is reflected by the surface of the drop opposite the side where it entered, and is then refracted again as it leaves the drop. When rays of light refracted in this way by millions of drops enter the eye, they are seen as a rainbow.

Experiment 116. To show how color is produced. Throw a solar spectrum on the screen as you did in Experiment 114. Hold a piece of red glass in the path of the light after it has passed through the prism. What happens to the solar spectrum? Substitute a piece of blue glass for the red glass. What happens?

When red glass was held in the path of the light, all the other colors disappeared from the spectrum. The red glass absorbed all of the waves of light except those which produce red. Explain what happened when blue glass was used. Any part of a ray of light which is not absorbed by the substance on which it falls is reflected (some of it may pass through), and the wave length of this reflected light determines the color of the substance. If the wave length of the sunlight reflected from a ribbon is .00047 mm., the ribbon is blue. A green dress looks green because only the light waves which give the sensation green are reflected to the eye. In general, therefore, an object looks red, blue, green, yellow, etc. in sunlight when it absorbs less of the light waves that produce one of these colors than it does of the light waves that produce the other colors contained in white light. The rays that are not absorbed are reflected to the eye and give the object its characteristic color.

The rays of light that are absorbed by a substance either produce chemical changes in the substance or are changed to heat waves. The change in a photographic plate is due to the chemical change produced by light rays. Girls are often dismayed to find that the chemical effects of light have faded the color of a beautiful dress. What sometimes happens to household furnishings and wall paper if they are exposed to direct sunlight? Can you suggest a reason why colored bottles are used in drug stores for certain medicines?

A black surface absorbs most of the light which falls upon it. A white surface, on the other hand, reflects a large fraction of the light which falls upon it. Can you explain why dark or black clothing is so much warmer, when worn in bright sunshine, than white clothing? Why is white clothing worn in tropical countries? In order to answer this question perform the following experiment.

Experiment 117. To discover whether dark-colored objects absorb more heat from the sun than light-colored objects. Smoke the outside of one test tube by holding it in the flame of a kerosene lamp. If the tube is moved back and forth in the flame, a smooth, even coat of carbon will be deposited. Place the test tubes side by side in a rack. Insert a thermometer in each and set the apparatus in the sunlight. After fifteen minutes read the thermometers. Which one has the higher reading? In which tube is the air the warmer? Explain. Answer the questions at the end of the preceding paragraph.

Problem: How Do We See?

The human eye. The organs of the body through which light waves produce the sensation of sight are the eyes. Our eyes are set in deep sockets in the bones of the skull. Each socket is lined with fatty tissue which acts like a cushion in protecting the eye from shocks. The eyes are shielded in front by movable folds of skin (*eyelids*) fringed with a row of stiff hairs which help to keep out foreign matter and help to shade the eyes from too intense light. If particles of dust, tiny insects, or other foreign matter get into the eye, or if a person is experiencing great sadness or joy, tears flow. If the flow is so great that it cannot all be drained away by the tear duct, the tears overflow upon the cheeks.

Structure of the eyeball. The human eye has the shape of a sphere about one inch in diameter. Figure 257 shows the outside coat. It is called the *sclerotic coat.* The part of it that can be seen normally is known as "the white of the eye." The sclerotic coat is opaque except in the front of the eye; there, it is transparent and is called the *cornea.* Why must the cornea be transparent? The sclerotic coat, including the cornea, is the only coat that completely surrounds the eyeball.

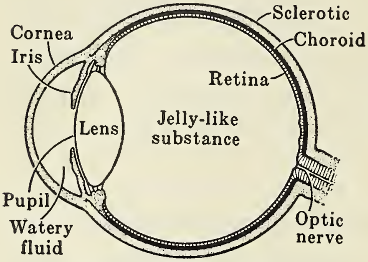


Fig. 257. The structure of the eyeball.

Beneath the sclerotic coat is the *choroid;* this coat contains a network of blood vessels and colored pigment cells that give it an appearance much like that of the inside of the skin of a dark grape. The dark surface of the choroid serves the same purpose as the lining of a camera. It absorbs rays of light that otherwise would be reflected back and forth in the eye and interfere with vision. In the case of an albino, a person whose eyes have little or no dark pigment cells, vision is imperfect in strong light. The part of the choroid coat at the front of the eye is the *iris.* It gives the eye its color, gray, brown, blue, black and the like.

In the center of the iris is a round opening, the *pupil,* through which light enters the eye. The size of the pupil is regulated by the muscles of the iris; these muscles make the pupil smaller when the light is bright and enlarge it when the light is dim.

The third layer of the eye, called the *retina,* is a sensitive mucous membrane connected with the *optic nerve* (the nerve of sight). It lines the interior of the eyeball except in front. The retina corresponds to the sensitive plate or film of a camera. It is the only part of the eye that is sensitive to light. Near the place where the optic nerve enters the eye there is a spot where the retina is thinner than at other places. This spot is the center of distinct vision. The place on the retina where the optic nerve and blood vessels enter the eye is not sensitive to light; that place is sometimes called the "blind spot" of the eye.

You may prove the presence of the blind spot in your eye by the use of Figure 258. Close your left eye and look steadily at the cross with your right eye, while holding the book directly in front of your face. Now move the book farther away from your eye and then back again, keeping the right eye constantly fixed upon the cross, and observe that the figures at the right of the cross disappear and reappear. When the light from the figures at the right falls upon the blind spot of your eye, the figures in turn disappear.

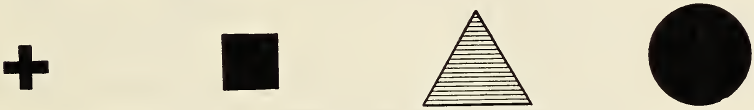


Fig. 258. Prove to your friends that there is a blind spot in the eye.

The larger part of the interior of the eyeball (Fig. 257) is filled with a colorless, transparent, jelly-like substance. In front of this substance and just behind the iris is a convex lens which serves to focus the rays of light upon the retina. Between the lens and the cornea is a small space filled with a clear, watery fluid. The shape of the lens is controlled by a set of muscles. In a normal eye, these muscles are so sensitive that they quickly change the thickness of the lens so as to bring the rays of light to a focus on the retina, regardless of the distance of the object.

How we see. When we look at an object, for example, a clock, rays of light reflected from the clock enter the eye through the cornea. They are refracted a little bit in passing from the air through the cornea and then they pass through a watery fluid behind the cornea to the lens. In passing through the lens, the rays of light are bent toward the thicker portion of the lens and passing through a jelly-like substance are brought to a focus on the retina (Fig. 259), where an image of the clock is formed. The image on the retina is transmitted to the brain by the optic nerve. The brain interprets these sensations as sight, and we say that we see the clock.

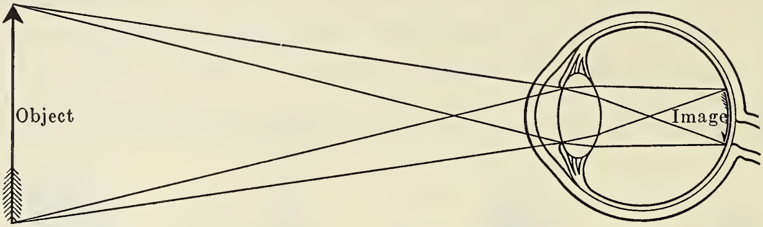


Fig. 259. Point out the parts of the eye that do the same work as the essential parts of a photographic camera (Fig. 255).

Figure 259 shows how an image is formed upon the retina. You observe that the image is inverted. You probably know that the slides used in a stereopticon must be placed in the lantern upside down if the picture on the screen is to be right side up. The fact that the image on the retina is always inverted does not prevent us from seeing the object in its correct position. The brain, which translates the effect of light on the retina into the sensation of sight, also produces a sensation of the object in its correct position. Scientists have not been able to explain just how light waves are translated by the brain into sight.

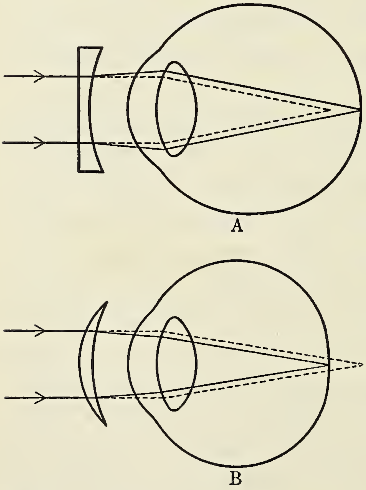


Fig. 260. What kind of lens is used to correct near-sightedness? far-sightedness?

Defects in sight. Because of one or more defects in the eye, light may not be focused on the retina. In an eyeball which is too long from the cornea to the retina, as shown in Figure 260A, the lens brings the rays of light to a focus in front of the retina, as indicated by the dotted lines in A. A person whose eyes are defective in this way is said to be *near-sighted;* he may not be able to see distant objects clearly without the aid of glasses.

An eyeball may be too short from the cornea to the retina (Fig. 260B), with the result that rays of light are brought to a focus behind the retina, as indicated by the dotted lines in B. A person whose eyes are defective in this way is said to be *far-sighted* or *long-sighted* and he, too, needs glasses to correct the defect.

Astigmatism is due to imperfections in the curvature of the cornea which causes a blurred image on the retina. This defect can also be corrected by glasses.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

albino
aqueous humor
astigmatism
choroid
concave
convex
cornea
corpuscles
developer
diffusion
ether
far-sighted
film
focus
image
incidence
iris
lens
microscope
mirror
near-sighted
negative
optic nerve
pupil
reflection
refraction
retina
sclerotic coat
spectrum
telescope
ultra-violet
vitreous humor

Write the number of each item on your paper and after it the word that completes the statement.

1. Light is a form of ________ energy.
2. Light travels at the rate of ________ per second.
3. An object is seen by light ________ from the object to our eyes.
4. The angle of incidence is ________ to the angle of reflection.
5. The bending of a light ray is called ________.
6. A lens is a transparent body that either ________ light or ________ light that passes through it.

7. The ________ of the eye is somewhat similar to that of the film or plate in a camera.

8. The amount of light entering the eye is regulated by the ________.

9. It is difficult to hit an object under water with a rifle bullet because of: convection; refraction; diffusion; reflection; incidence of light.

10. The pupil of the eye is formed by the opening in the: retina; aqueous humor; cornea; sclerotic coat; iris.

Which of these statements are true? If any are false, re-state them in correct form.

11. Snow under a black cloth would melt faster in sunshine than snow under a white one.

12. X-rays are very necessary to maintain the health of people.

13. Edison first calculated the speed of light.

14. Mirrors are the best reflectors of light.

15. When a ray of light is scattered it is said to be diffused.

16. The technical name for the bending of light is reflection.

17. The nerve of sight is the auditory nerve.

18. The cornea gives color to the eye.

19. All lenses are made of glass.

THOUGHT EXERCISES FOR UNIT XI

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Light is a form of radiant energy.

Questions or Problems

1. Is the sun the source of all light? Discuss your answer.

2. Why does electricity tend to replace all other forms of artificial lighting?

3. Is the moon incandescent?

4. The shadow of a tree is longer at 4 P.M. than at 2 P.M. Why?

5. Why does an eclipse of the moon occur more often at a given place than an eclipse of the sun?

6. What principle of science is made use of in a periscope?

7. Why is an inactive gas used in a tungsten lamp?
8. What causes a rainbow?
9. Why do fish often appear to change in size in an aquarium?
10. A person cannot see his image in a rough board. Why?
11. Why does a red ribbon appear red?
12. Is there anyone in your class being benefited now by a lens?

PROJECTS AND REPORTS

1. Make a study of the lighting of your school building. Prepare a paper discussing its merits and defects.

2. Study the history of artificial lighting. Collect exhibits and pictures of lamps to show to the class. Discuss the advantages and disadvantages of each.

3. Set up apparatus to demonstrate to the class the advantages and disadvantages of the three types of lighting fixtures for doing different types of work.

4. If a moving picture machine is available study its construction and learn how it works.

5. Make a pin hole camera and demonstrate it to the class.

6. Take a series of photographs, develop and print the pictures. Show to the class the parts of the camera, and explain the function of each part. Discuss the materials used in developing and printing the photographs.

7. Construct a periscope and demonstrate its use before the class.

REFERENCES FOR READING AND STUDY

1. Bragg, Sir William, *The Universe of Light.* The Macmillan Company.

2. Broadhurst, Jean, and Lerrigo, Marion Olive, *Health Horizons,* Section XV, Light and Health. Silver Burdett Company.

3. Darrow, F. L., *Thinkers and Doers,* Chapter XII, History of Developing the Photograph. Silver Burdett Company.

4. Eastman Kodak Co., Rochester, N. Y., *How to Make Good Pictures.*

5. Gibson, Chas. R., *Photography and Its Mysteries.* Seeley, Service & Co., Ltd.

6. Houston, E. J., *The Wonder Book of Light.* W. & R. Chambers, Ltd.

7. Ilin, M., *Turning Night Into Day.* J. B. Lippincott Company.

8. Luckiesh, M., *Artificial Light.* D. Appleton-Century Company.

9. Meister, Morris, *Energy and Power,* Chaps. I to VI. Charles Scribner's Sons.

10. Mowry, Wm. A. and May, Arthur, *American Inventions and Inventors,* Chapter II. Silver Burdett Company.

11. Parker, Bertha M., *The Book of Electricity,* pp. 138–160. Houghton Mifflin Company.

12. Tappan, Eva M., *Wonders of Science,* School Edition, pp. 478–482, "The Greatest Camera in the World," by Edward Arthur Fath. Houghton Mifflin Company.

UNIT XII

HOW HAS ELECTRICITY BECOME MAN'S GREATEST SERVANT?

Exploring the World of Electricity

When you enter a room at night you push a button or turn a lever and the room is flooded with light. If you are hungry, you may go to an electric refrigerator and get a glass of cold milk to satisfy your needs. If a room seems cool, you may turn on a heater whose glowing wires give you warmth and cheer. In a home the power used to do laundry work, to wash dishes, to cook, and to do many other things may be secured by pushing or turning switches. Before you can start an automobile, the same kind of power must be turned on before the engine will run. Modern trains use this power to travel across the country with amazing speed. Even ocean liners use it as they cross the seas. Have you ever wondered about this mysterious force which produces the power that man uses to do his work?

In ancient times when Aladdin wanted anything, he touched his magic lamp and according to tradition genii suddenly appeared to do his bidding. In modern times when we want certain things, we touch a button and electricity does our bidding. After years of patient work, scientists have brought the power of distant streams, coal mines, and oil wells into our cities and countryside in the form of electricity. Electricity makes Aladdin's lamp a reality in our modern civilization. Undoubtedly, it will do more wonderful things in the future than it has in the past.

CHAPTER XXIII

WHAT IS ELECTRICITY AND HOW IS IT GENERATED?

Do you know:

That sometimes you can get an electric shock when you shuffle across a rug and then touch a radiator? Why your hair sometimes clings to a comb when you comb your hair? That lightning is a gigantic spark of electricity? What causes thunder? What an electric current is? That electricity can be generated by chemical action?

That a compass needle is a magnet? That the earth is a huge magnet? How a bar magnet differs from a horse shoe magnet? That like poles of a magnet repel each other? That unlike poles of a magnet attract each other? That electricity can be generated by turning a coil of insulated wire in a magnetic field? That a wire carrying an electric current is surrounded by a magnetic field? Why a transformer is used in an electric circuit? That a fuse in an electric circuit is really a safety device?

PROBLEM: WHAT IS AN ELECTRIC CHARGE AND HOW CAN IT BE PRODUCED?

What is electricity? Electricity cannot be seen or handled like a material substance. You have, no doubt, rubbed the end of a fountain pen on your clothing and then used the pen to attract bits of paper; or you may have run a comb rapidly through your hair several times and then passed it over bits of paper, thus making them jump and dance. The Greeks knew that amber, which they called electron, would attract bits of material in this way if rubbed with a piece of cloth. They could not explain why amber should do so; but we know that it was due to an electric charge.

Inside the atom. Modern scientists tell us that an atom is made up of a definite number of electric charges. Each atom has a nucleus, consisting of a number of charges of one kind of electricity, called positive electricity, and of a lesser number of another kind, called negative electricity. Grouped around this nucleus are charges of negative electricity. The nucleus and the surrounding negative charges make up the atom. A charge of negative electricity is called an *electron*, and a charge of positive electricity is called a *proton*.

What materials will conduct electricity? The structure of the atoms of metals such as silver, copper, and iron permits electrons to move freely. A material such as a metal which permits electrons to move readily is said to be a *conductor* of electricity. The structure of the atoms in glass, rubber, porcelain, shellac, dry air, wood, and oil does not permit electrons to move freely. Consequently, a material such as one of these is a poor conductor of electricity, and is called a *non-conductor* or *insulator*.

How can you produce an electric charge? If, when air is dry, you shuffle rapidly over a heavy rug and then hold your finger close to a register or radiator, a spark will jump between your finger and the metal. Have you ever had this experience? If you have, you have produced an electric charge. As you perform the following experiment you will need to remember that a substance which has an electric charge will attract light bodies.

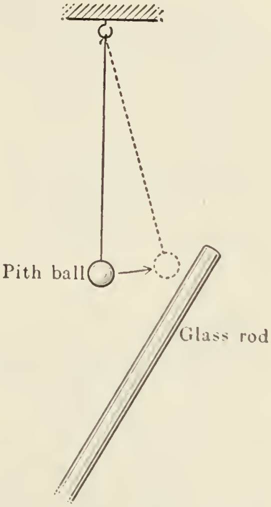


FIG. 261. What is the reason for the movement of the pith ball?

Experiment 118. To produce electric charges. Rub a glass rod with a silk cloth; hold the glass rod near a suspended pith ball or a very small piece of cork (Fig. 261). Be careful not to let the pith ball touch the rod. What happens? Bring the silk cloth near the pith ball. What happens?

Now rub a piece of sealing wax or a hard rubber rod with a woolen cloth or a piece of fur, and hold it near the pith ball. What happens? Does the woolen cloth or the fur also attract the pith ball?

From this experiment and many similar ones scientists have concluded that as two substances are rubbed together each of them receives electric charges.

It has been proved by many tests that the electric charge produced on a glass rod is different from the electric charge produced on the rubber rod. Franklin named the electric charge produced on a glass rod by rubbing it with silk cloth *positive electricity*, and the electric charge produced on a rubber rod by rubbing it with woolen cloth *negative electricity.*

Experiment 119. To observe how positive and negative electric charges act toward each other. (a) Suspend two pith balls as shown in Figure 262. Produce a positive electric charge by rubbing a glass rod with silk. Touch each of the pith balls with the glass rod. What happens?

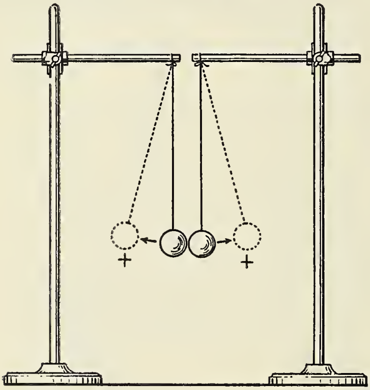


FIG. 262. Like electric charges repel each other.

When the balls were touched with the glass rod, each received a positive electric charge. Do two positively charged pith balls attract or repel each other?

(b) Charge the pith balls with negative electricity from a rubber rod rubbed with fur. What happens? Do two negatively charged pith balls attract or repel each other?

(c) Move the standards from which the pith balls are hung farther apart. Charge one with positive electricity and the other with negative electricity. Bring the two pith balls nearer each other. What happens? Does a positively charged pith ball attract or repel a negatively charged pith ball?

From this experiment and many similar ones scientists have concluded that when two substances are charged with the same kind of electricity they repel each other; but that when one has a positive charge and the other a negative charge, they attract each other. We say, therefore, that:

Like charges repel each other.
Unlike charges attract each other.

What causes an electric charge? When the surface of a substance has exactly the same number of positive charges as it has negative charges, the action of the positive charges neutralizes the action of the negative charges and the surface acts as if it had no charges at all. When the glass rod was rubbed with silk cloth, some of its electrons (negative charges) were rubbed off the rod on to the silk. The rod then lacks the number of electrons necessary to neutralize the positive electric charges. The glass rod has lost some of its electrons and is said to have a positive electric charge.

As the electrons rubbed off the glass rod are on the silk cloth it has an excess of electrons. The silk cloth has gained electrons and is said to have a negative electric charge.

When the hard rubber rod was rubbed with a woolen cloth, some of its electrons were rubbed off the cloth on to the rod. Did the rod receive a positive or a negative charge? Is the woolen cloth positively or negatively charged?

Electric charges in our daily life. The electric charges on the rubber rod and the glass rod were caused by rubbing, that is, by *friction.* When you rub your hand briskly over the fur on a cat's back, crackling sounds may be heard. These are caused by small charges of electricity jumping between your hand and the cat's fur. If you hold your finger near a large moving belt in a factory, sparks may be seen between the belt and your finger. These electric charges are produced by friction due to the belt's rubbing on the pulley. A printer sometimes experiences difficulty in picking up a sheet of paper from a pile as they cling together because unlike electric charges have been produced on them by friction as one sheet rubs on the other. During a thunderstorm it is thought that powerful upward gusts of wind break up large drops of water into fine spray. When this is done positive and negative electrical charges are produced. This accounts for electrical charges sufficiently large to produce lightning. When the discharge passes from a cloud to a cloud, or from a cloud to the ground, the large electric spark called *lightning* is produced.

Franklin's experiment. Nearly all young people are interested in the experiment performed by Franklin in 1752. Franklin had believed for some time that lightning was a great spark of electricity. To test his theory he devised the following experiment. During a thunderstorm he flew a kite having at its top a pointed metal rod. He used a linen kite string because linen, when wet, is a conductor of electricity. The lower end of the string was attached to an insulator to prevent any electric charges which might accumulate on the kite from being conducted to the ground. Franklin reasoned that electric charges would accumulate on the kite, string, and key which he attached to the string near the ground. When Franklin brought his finger near the key, electric sparks passed between the key and his finger (Fig. 263). From his experiment Franklin concluded that lightning is a great electric spark produced by electric charges in the air.

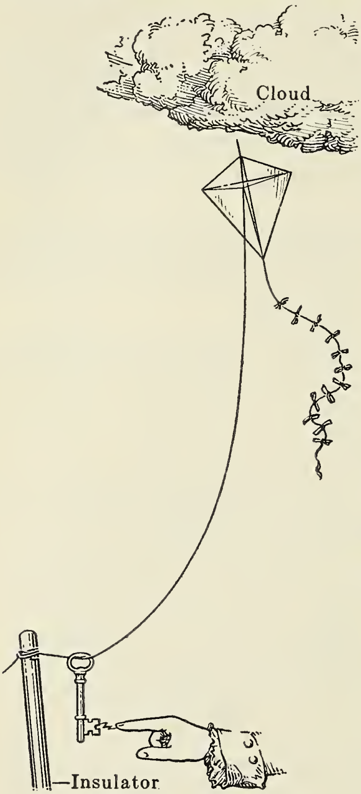


Fig. 263. Did Franklin's experiment prove that lightning is a great spark of electricity?

What is a lightning rod? Now that he had discovered the nature of lightning, Franklin set about to find some means of protecting buildings from damage by it and so invented the *lightning rod.* A lightning rod usually consists of a pointed copper rod extending from the highest point of a building to the ground. A lightning rod, if properly fastened to a building and extended far enough into the ground to reach moist earth, will usually protect a building from the destructive effects of lightning.

To understand how a lightning rod acts, let us suppose that a cloud charged with one kind of electricity is attracting a charge of the other kind of electricity on the earth beneath it. The tendency of these unlike charges is to move as near as possible to each other. If they move close enough together and are large enough, the attraction of one for the other may become strong enough for them to break through the air. Since the charge on the earth tends to get as near the unlike charge on the cloud as possible, the electric charge will be greatest on the tops of buildings, trees, and on hill tops. Therefore, lightning rods are installed on the highest points of buildings to allow the charge on the earth to pass harmlessly into the air in small amounts. Because electric charges on a pointed rod tend to flow off the rod as fast as formed, a lightning rod usually prevents the accumulation of a charge strong enough to produce lightning. If lightning should strike the rod, probably it would be conducted to the ground along the copper wire without causing damage.

What is thunder? The sound known as thunder, which accompanies a flash of lightning, is caused by the violent explosion of the air along the path of the discharge. The explosion results from intense heating and the disintegration of molecules to atoms and atoms to electrons.

Problem: What Is an Electric Current and How Is It Produced?

What is an electric current? As you know, electrons, or charges of negative electricity, will pass along a conductor such as a copper wire. A stream of electrons moving along a conductor forms what is called an *electric current.* When the conductor forms an endless path for the electrons, it is called a *circuit.* The movement of electrons through a circuit may be compared to the movement of a line of soldiers in single file; each soldier taking one step forward produces a movement along the entire line. The whole forward movement of electrons becomes a sort of march around the circuit. If the circuit is broken, that is, if the conductor is broken or disconnected at any point, the path for the electrons is broken and they cease to move forward. The current stops. The march goes on again only when the circuit is completed.

How is an electric current produced by a voltaic cell? Electricity had been known for about two thousand years before men learned how to conduct it as a current through a circuit. Two men, Galvani (1786) and Volta (1792), each working by himself, discovered that two different metals placed in a dilute solution of acid and connected by a wire will produce a current of electricity. This current passes through the wire from one metal strip to the other. Such an apparatus is called a *voltaic cell.*

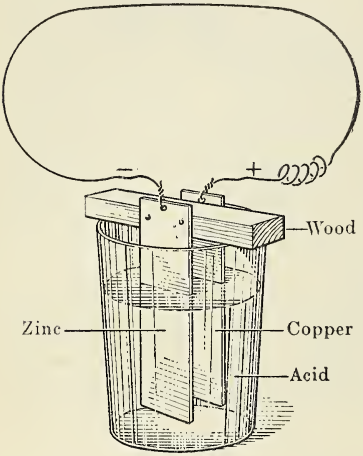


FIG. 264. Does the block of wood in this voltaic cell serve any other purpose than to hold the metal strips?

Experiment 120. To make a voltaic cell. Procure two strips of clean sheet metal, one of copper and one of zinc, each about 1 by 4 inches. Make a hole near one end of each strip and fasten a short copper wire to each. Now nail the strips to a block of wood (Fig. 264) long enough to extend across the top of a glass. Suspend the metal strips in the glass as shown. Fill the glass about two-thirds full of dilute sulfuric acid. Connect the two wires and observe what happens. Hold the wire above a compass. What happens?

The turning of a compass needle when brought near a wire is one of the tests by which we can tell that an electric current is flowing through the wire. The chemical action that you saw taking place within the voltaic cell is due to the action of the acid on the zinc. The copper and zinc strips are called *electrodes* or *poles;* the copper strip is the *positive pole* and the zinc strip is the *negative pole.* The dilute solution of sulfuric acid is called the *electrolyte.*

The chemical action causes a flow of electrons to move in the acid from the positive pole (copper) to the negative pole (zinc). From the negative pole the electrons move through the wire to the positive pole, thus producing an electric current.

Before the discovery and study of electrons, it was thought that the current through the wire flowed from the positive pole (copper strip) through the copper wire to the negative pole (zinc strip). Inside the voltaic cell the current was thought to flow from the negative pole to the positive pole. It was customary, then, to say that an electric current flowed through a wire from the positive pole to the negative pole. For many years this explanation of an electric current was generally accepted and used in speaking and writing of electric currents. You must remember, however, that in an electric circuit electrons move through the connecting wire from the negative pole to the positive pole.

Experiment 121. To find out what substances are used to make a dry cell. Procure a worn out *dry cell* (Fig. 265) and remove the cardboard case. You will observe that the outside of the cell consists of a zinc can. Notice, too, that one of the binding posts (places where wires are fastened) is attached to the zinc can. It may be that you will find holes in the zinc can. What caused these holes? Why was a cardboard case used?

The top of the cell may be a layer of sealing wax or pitch, or there may be two layers, one of each. The purpose of these layers is to seal the can so that its contents cannot escape, and to act as an insulator between the poles. Remove these layers. It may be necessary to use a chisel. You may now discover, beneath, another layer either of sand or sawdust or both. These are used chiefly as "fillers." Next you will come to a black mixture.

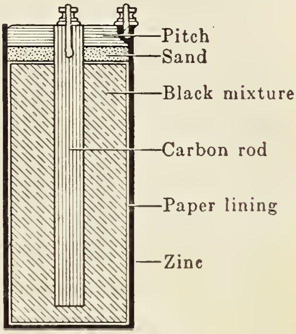


FIG. 265. Structure of a dry cell.

This mixture is not the same in all cells, but generally it is made up of manganese dioxide, zinc chloride, powdered carbon, ammonium chloride, a small amount of graphite, and enough water to form a paste. The pole in the middle of the cell, which can be taken out now, is the positive pole. You will observe that it is a carbon rod. Notice, too, that a porous paper lining separates the black mixture from the zinc can. How does the moist chemical mixture come into contact with the zinc can?

How is an electric current produced by a dry cell? If you put a bit of ammonium chloride in a test tube containing water, you will observe that it dissolves. In the same way the ammonium chloride in a dry cell dissolves in the water in the mixture. This ammonium chloride solution filters through the porous paper lining the cell, and, upon coming into contact with the zinc, changes some of the inner surface into zinc chloride, the white powder which you noticed in the holes in the zinc can.

The chemical energy released when zinc is acted upon by the ammonium chloride solution is changed into electric energy. This electric energy is a flow of electrons through a conductor that connects one pole with the other.

The chemical action occurs and the electric current is produced only when the circuit is completed by attaching a wire from one binding post to the other.

A number of cells, either dry cells or voltaic cells, joined together so that they can be operated as a unit is called a *battery.*

Uses of electric cells. The use of electric cells to produce large quantities of electric energy would be very expensive. Consequently, electric cells are used only to produce small currents needed for short periods,—such as are needed to operate door bells, telephones and telegraphic instruments, certain kinds of radios, flashlights, and other devices.

What are the units used for measuring electric current? Just as it is necessary to have units to measure length, so it is necessary to have units to measure an electric current. Since an electric current is invisible, it cannot be measured directly, i.e., as one would measure the length of a rod. We must measure it indirectly, that is, by one of its effects.

If a uniform current of electricity is passed through a solution of silver nitrate, silver will be deposited on the negative pole at a uniform rate. This is the effect chosen to measure the amount of current. The unit is defined as the amount of current necessary to deposit 0.00111800 gram of silver in one second. It is named in honor of a French scientist, Ampere. The instrument used to measure an electric current in amperes is the *ammeter.*

An electric current flowing through a wire may be compared to a stream of water flowing through a pipe. A certain quantity of water flowing through a large pipe meets with much less resistance than the same quantity of water flowing through a small pipe. Ohm, a German scientist, discovered that an electric current flowing through a small wire meets with more resistance than the same current flowing through a larger wire. He discovered, also, that wires of different materials offer different amounts of resistance to the flow of the same amount of electric current. For example, an iron wire offers more resistance to the flow of an electric current than a copper wire of the same size; and a copper wire offers more resistance to the flow of an electric current than a silver wire of the same size. The unit of resistance is the *ohm.* It is the resistance offered by a column of mercury of certain dimensions and at a certain temperature. About 39 feet of No. 24 copper wire offers a resistance of 1 ohm.

Pressure is needed to force water to flow through a pipe. Similarly pressure is needed to force electricity to flow through a circuit. The unit of electric pressure is a volt. A *volt* is the electric pressure which can force an electric current of 1 ampere to flow through a conductor having a resistance of 1 ohm. It is named in honor of the Italian scientist, Volta. A single voltaic cell has an electric pressure of about 1 volt; a dry cell develops a pressure of about $1\frac{1}{2}$ volts. The instrument used to measure volts is the *voltmeter.*

Ohm's law. One of the first laws of electric currents was discovered by Ohm. This law expresses the relation between current, voltage, and resistance as follows:

$$\text{Current} = \frac{\text{Electric pressure}}{\text{Resistance}}.$$

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}.$$

According to this law, will an electric pressure of 8 volts in a circuit of 2 ohms resistance give a current of $\frac{8}{2}$ or 4 amperes?

Special problem. Find the resistance of an electric lamp that operates on a 110-volt circuit and uses $\frac{1}{2}$ ampere of current.

How is electric apparatus connected in series? If a number of "pieces" of electric apparatus are connected in the same circuit so that the current passes first through one piece then another and so on until it gets back to the first piece, the pieces of apparatus are said to be connected in *series*. The lamps on a Christmas tree are usually connected in series. Electric lamps for street lighting are sometimes connected in series. When they are, the electric current that passes through one lamp must pass through all the other lamps in the circuit. In such a circuit, if one lamp is removed, the circuit is broken, and, therefore, electricity ceases to flow through the other lamps in the circuit.

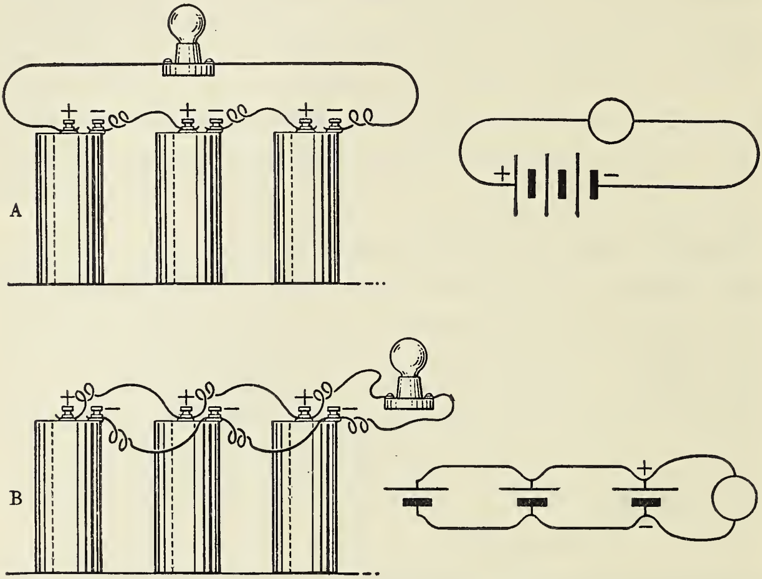


Fig. 266. A, dry cells connected in series; B, dry cells connected in parallel.

To connect cells in series (Fig. 266A), the positive pole of one cell is connected to the negative pole of the next cell, and so on until all the cells are connected. When cells are connected in series does the current from one cell pass through every other cell in the circuit?

How is electric apparatus connected in parallel? If a number of pieces of electric apparatus, for example a number of lamps, are connected in the same circuit so that the current divides as it comes to the first lamp, part of the current passing through the lamp and the remainder flowing on through the circuit, the lamps are said to be connected in *parallel.* The current divides in the same way as it reaches each of the other lamps in the circuit. The current divides in the same way when electric apparatus of any kind is connected in parallel.

When electric apparatus is connected in parallel the amount of current that flows through a particular piece of apparatus depends upon the resistance it offers to the flow of electricity. When electric apparatus in a circuit is connected in parallel one piece of apparatus can be turned off (cut out of the circuit) without interfering with the flow of electricity through the others. The parallel system of connecting electric apparatus, therefore, is used in our homes and in factories, so that an individual lamp, a heating device, motor, and the like, can be turned on or off without affecting the operation of the others.

To connect cells in parallel (Fig. 266B) all positive poles are connected, forming the positive pole of the battery, and all the negative poles are connected, forming the negative pole. This makes it possible for the current from one cell to go out into the circuit without passing through the other cells.

Problem: What Is Magnetism and How Are Iron and Steel Magnetized?

More than two thousand years ago people discovered that pieces of a certain ore would attract bits of iron. Because a piece of this ore when hung so that it is free to turn, always points north and south, it is called a *lodestone*, meaning "leading stone." It is thought that lodestones were first discovered in Magnesia, in Asia Minor, hence the name magnet. Lodestone, a compound of iron and oxygen, is found also in Norway, Sweden, and on the American continents.

What is an artificial magnet? After a piece of iron or steel has been stroked with a lodestone it will attract other bits of iron or steel. Such a piece of iron or steel is said to be magnetized and is called an artificial *magnet.* An artificial magnet may, in turn, be used to magnetize other pieces of iron or steel. Later we shall learn how an artificial magnet may be made by an electric current (page 448). A bar magnet is an artificial magnet in the form of a bar; a horseshoe magnet is one in the form of a horseshoe.

Experiment 122. To study the properties of a magnet. Suspend a lodestone by a string in such a manner that it is free to turn (Fig. 267).

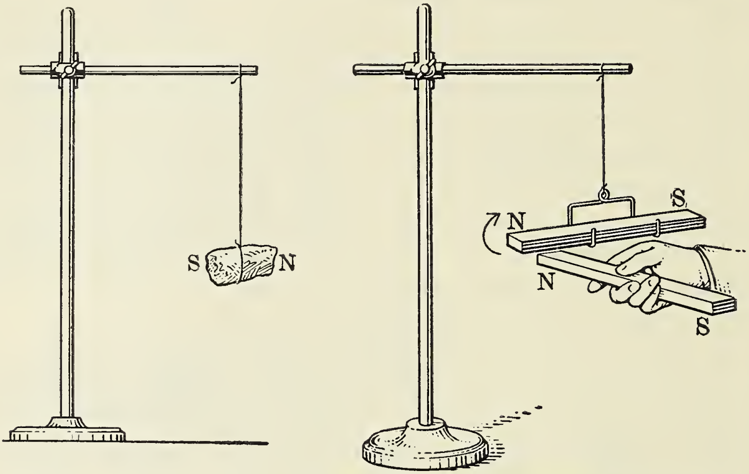


FIG. 267. What position does a magnet assume when free to turn? What effect does bringing a second magnet near it have? Why?

After the lodestone has stopped turning, notice in what direction it points. Start it turning again and allow it to come to rest. Where does it point now? Start it turning again. What happens?

Now suspend a bar magnet and notice after three trials in what direction the magnet points when it comes to rest. Observe the letters stamped on the ends of the bar magnet. What do they mean?

Experiment 123. To find the poles of a bar magnet. Place a bar magnet on a sheet of paper and pour iron filings over it. Lift the magnet and notice the places where most of the filings are clinging.

Try the same experiment with a horseshoe magnet if one is available.

The places where most of the filings cling to a magnet are called the *poles* or the magnetic poles of the magnet. The pole of a bar magnet that points toward the north when the magnet is free to turn is called the north seeking pole, or the *north pole;* the opposite end of the magnet is called the south seeking pole, or the *south pole.*

Experiment 124. To study the effect of the poles of one magnet upon the poles of another magnet. Suspend a bar magnet so that it is free to turn (Fig. 267). Bring the north pole (N) of another bar magnet near the north pole of the suspended magnet. What happens? Find out what happens when their two south poles are brought near each other. Now bring the south pole of one magnet near the north pole of the other. What happens?

From this experiment we conclude that:

Like magnetic poles repel each other, and unlike magnetic poles attract each other.

This conclusion is known as the *law of magnetic poles.*

The earth as a magnet. Thus far in our study of magnetism we have noticed that whenever a bar magnet is suspended and is free to turn, it comes to rest in a north and south line, with the north pole pointing to the north and the south pole to the south. The law of magnetic poles suggests that there is a south magnetic pole somewhere in the northern part of the earth which is attracting the north pole of the magnet.

Similarly there seems to be a north magnetic pole somewhere in the southern part of the earth. This is actually the case. Dr. William Gilbert was the first to advance the theory that the earth is a magnet and to suggest that the earth's magnetism explained the behavior of magnets free to turn.

Although the magnetic pole in the northern hemisphere has the properties of a south magnetic pole, we call it the north magnetic pole of the earth because of its location. The magnetic pole in the southern hemisphere is called the south magnetic pole of the earth.

The north magnetic pole was first located in 1831 by Sir James Ross; in 1905 it was re-located slightly farther west by Captain Amundsen. Investigations made in the north polar regions have led to the conclusion that the north magnetic pole may alter its position slightly or it may move over a considerable area. However, it is agreed that this pole is situated slightly northwest of Hudson Bay and about 1000 miles from the geographic north pole.

According to the United States Coast and Geodetic Survey, the approximate position of the north magnetic pole is in latitude 70.8° N. and longitude 96° W. The south magnetic pole was first located in 1912 by Captain Amundsen. The position of this pole has been estimated to be in latitude 72.7° S. and longitude 156° E. Find these poles on a map or globe.

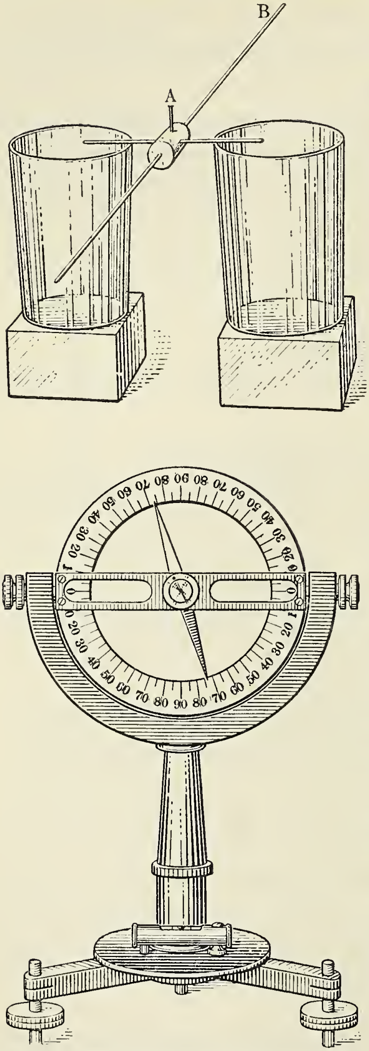


FIG. 268. The apparatus shown at the top is a home-made dipping needle. Balance needle *B* before magnetizing it. Will it still balance after being magnetized? Why not? A commercial dipping needle is shown at the bottom.

Special problem. A magnetic dipping needle is shown at the bottom of Figure 268. Construct a dipping needle as shown at the top. Test the effect of the poles of a magnet on this needle by placing a bar magnet in different positions on the table near the needle. Explain the purpose of each part of the instrument. Could a dipping needle be used to locate the magnetic poles of the earth? Explain.

What is a compass? You learned in Experiment 122 that a bar magnet, suspended so that it is free to turn, always comes to rest in a north and south line. We make use of this behavior of a bar magnet to construct a *compass*. In a compass a strongly magnetized needle is balanced accurately on a pivot; consequently it is free to turn in a circle. If a compass is held parallel to the earth's surface, its needle always points north and south. Explain how you could use a compass to tell whether you were walking south; west; east. Compasses are used by navigators, explorers, hunters, and by many others.

We have all read of the alarm of the sailors with Columbus when they discovered that the compass no longer pointed exactly north, that is, to the geographic north pole. The reason for this is, of course, the fact that the north magnetic pole (to which the compass points) and the geographic north pole are not located at the same place. In the eastern part of the United States a compass points a little west of north; in the western part it points a little east of north. Explain.

What are the "northern lights"? Perhaps you have seen the beautiful northern lights (aurora borealis). It is thought the northern lights are caused by an electric discharge in the upper regions of the atmosphere. Explorers tell us that the streamers of the northern lights meet at the north magnetic pole, indicating that this beautiful electric display may be caused by the magnetism of the earth.

What is induced magnetism? As we need to learn how certain electric machines, such as the motor, generator, and transformer operate, we must first find out what is meant by induced magnetism.

Experiment 125. To show induced magnetism. Pick up a nail with the end of a bar magnet. Touch a second nail to the free end of the first. Does the first nail hold up the second? Try to suspend a third nail to the second. What can you suggest to explain the action of these nails? Now hold the first nail firmly, and carefully slide the bar magnet away from it, taking care not to jar the other two nails. What happens? Suggest a reason.

In Experiment 125 the first nail became a magnet when touched to the bar magnet. It in turn magnetized the second nail. Did the nails separate when the bar magnet was removed from the first nail? The nails were magnets only as long as they were in contact with the bar magnet. When a piece of iron touches or is brought close to the pole of a magnet it becomes a magnet by *induction*.

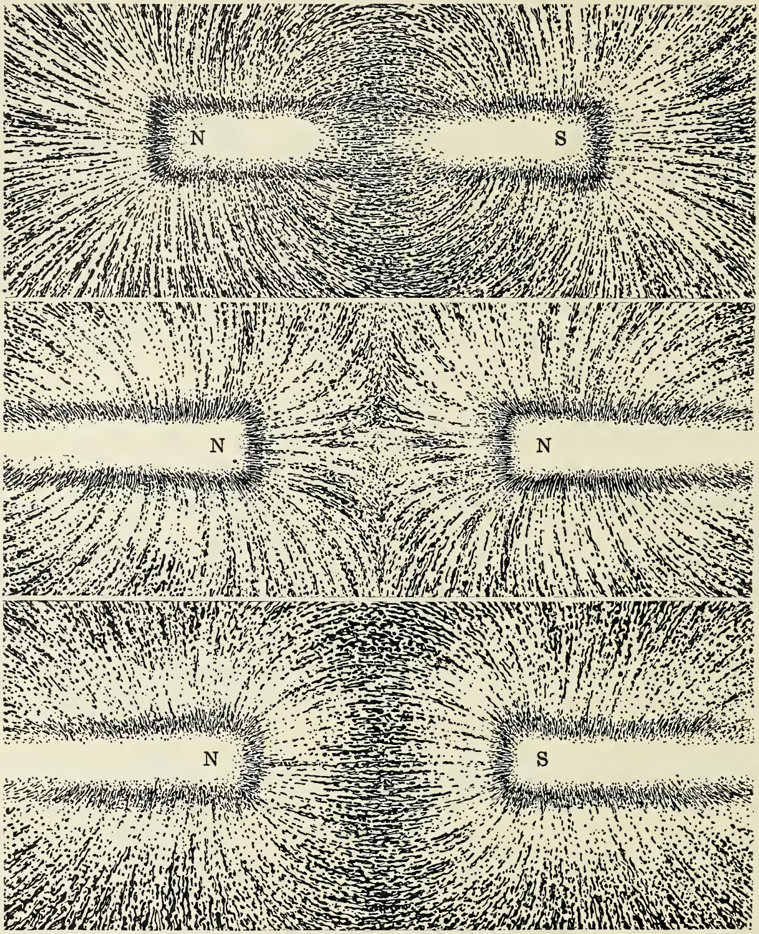


Fig. 269. Explain what happens to the lines of magnetic force when like poles of two magnets are brought near each other; when unlike poles are brought near each other.

Experiment 126(a). To show the magnetic field of a bar magnet. Lay a small bar magnet on the table and cover it with a piece of paper. Sprinkle fine iron filings on the paper. Tap the paper gently. What happens to the filings? Are they arranged as the filings are in the drawing at the top? What causes them to so arrange themselves?

The magnet exerts a force on the filings which causes them to arrange themselves as shown in the drawing at the top in Figure 269. Each iron filing has become a magnet by induction. The space around a magnet in which the magnet exerts a force and does work on the iron or steel filings is called a *magnetic field.* Scientists believe that invisible *lines of magnetic force* extend in space from the north pole of a magnet to its south pole and then through the magnet to the north pole again. Because the filings are tiny magnets they assume a position parallel to these lines of force. The lines formed by the filings, then, represent the lines of force in the magnetic field.

Experiment 126(b). To show magnetic fields. Sprinkle iron filings on a paper covering two magnets with like poles near each other. How are the lines of magnetic force arranged? How do they compare with the lines of magnetic force shown in the middle drawing in Figure 269?

Experiment 126(c). To show magnetic fields. Sprinkle iron filings on a paper covering two magnets with unlike poles near each other. How are the lines of magnetic force arranged? How do they compare with those in the lower drawing in Figure 269?

Experiment 127. To show the nature of magnetism. (a) Make a small magnet by rubbing a piece of watch spring or steel wire on a magnet. Use filings or small nails to test its magnetism. Heat the small magnet and then test its magnetism. How did heating affect its magnetism?

(b) Make another magnet; test its magnetism; hammer it; and then test its magnetism again. How did hammering affect its magnetism?

(c) Fill a small test tube with iron filings and stroke the tube with a magnet. What happens to the filings? Bring the tube filled with filings near a compass needle. What happens? Does the tube act as a magnet? Shake the tube and again bring it near a compass needle. Does it act as a magnet now? How did shaking the tube affect its magnetism?

When the test tube was stroked each iron filing became a magnet. Continued stroking caused these tiny magnets to arrange themselves each with its north pole turned in one direction. The combined action of these small magnets caused the test tube full of them to act as though it were a single magnet.

As iron and steel can be magnetized to a considerable degree, it is believed that their molecules are at all times tiny magnets.

When these molecules are so arranged that a large majority of their north poles point in the same direction (Fig. 270) the piece of iron is said to be magnetized. If these molecules when so arranged are disturbed by any force the magnetized iron or steel loses part or all of its magnetism.

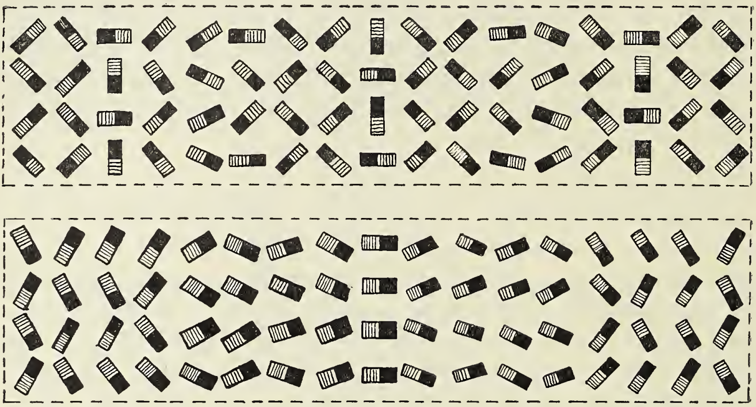


FIG. 270. Which of these iron bars is the stronger magnet? Why?

If a bar of hardened steel is magnetized, its molecules may retain their rearranged position for years; we call such a bar a permanent magnet. If a piece of soft iron is magnetized, the position of the molecules can be disturbed so easily that we speak of it as a temporary magnet. Both permanent and temporary magnets are used widely in modern industry.

PROBLEM: HOW IS AN ELECTROMAGNET MADE AND WHAT ARE ITS USES?

In the foregoing experiments the force that rearranged the molecules in the watch spring and in the iron filings so as to produce a magnet was the magnetic force of other magnets. Electric energy may be used to rearrange molecules of iron and steel so as to produce a magnet. This is the way that magnets which are used for commercial purposes are generally produced.

Experiment 128. To show that a wire carrying an electric current affects a compass needle. Connect two dry cells in series with insulated wire (Fig. 271). Leave one end of the wire so that you can close or open the circuit at will. Hold the wire above a compass needle. Is there any change in the position of the needle? Now touch the wire to the binding post of the cell so that a current will pass through the wire. What happens to the compass needle? Reverse the current. Hold the wire above the compass needle. What happens to the compass needle now?

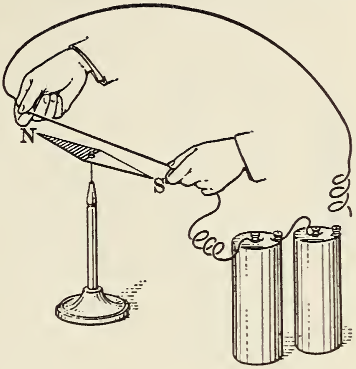


Fig. 271. When the circuit is completed, what is the effect on the magnetic needle?

We learn two facts from this experiment. When a current of electricity passes through a wire it sets up a magnetic field about the wire (Fig. 272) which is indicated by the turning of the compass needle. The direction taken by the lines of magnetic force can be controlled by changing the direction of the current, as was shown by the fact that the needle turned in the opposite direction when the current was reversed.

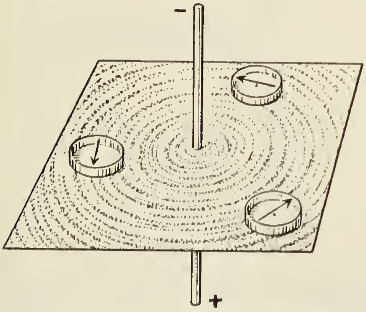


Fig. 272. Follow the idea shown here to find the direction of lines of force around a wire carrying a current.

Experiment 129. To show that a coil of insulated wire carrying a current has a N-pole and a S-pole like a bar magnet. Wind several turns of insulated wire around a pencil. Attach the ends of the wire to a dry cell. Bring a compass near one end of the coil. What happens? Is the N-pole or the S-pole of the compass attracted to this end of the coil? Bring the compass near the other end of the coil. Which pole of the compass is attracted? Does the coil act like a magnet when the current is passing through it? Where is its north pole? Its south pole?

Experiment 130. To show the effect produced when a soft iron rod is placed in a coil carrying an electric current. Wind a coil of insulated wire around a soft iron rod (a large nail may be used for the iron rod) and attach the ends of the wire to a dry cell (Fig. 273). Lay the rod and coil on the table and find the farthest point at which a compass needle is affected by the magnetic field.

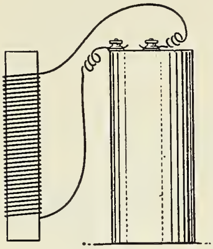


FIG. 273. How can you find the N-pole of this magnet?

Slide the iron rod out of the coil. Is the compass needle still affected by the magnetic field? Move the compass nearer the coil until it is affected. Does the soft iron rod increase the strength of the magnetic field of the coil of wire through which an electric current is flowing?

An *electromagnet* is made of a coil of insulated wire wound around a soft iron rod called a *core*. The iron is magnetized when the current flows through the wire and thereby becomes a temporary magnet.

Experiment 131. To make an electromagnet and study its properties. Wind several turns of insulated wire around a bar of soft iron (Fig. 274). Attach the ends of the wire to a dry cell. Touch one end of the bar to tacks, nails, and small pieces of iron. What happens?

Compare the lifting power of the magnet when there are a few turns of wire in the coil and when there are several more turns of wire. What do you find? Compare the lifting power of the magnet when it is attached to one dry cell and when it is attached to two dry cells in series. What do you find?

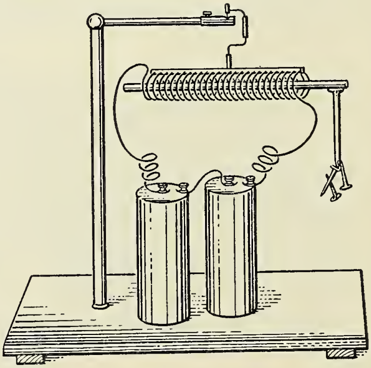


FIG. 274. What will happen to the nails and tacks if you disconnect the dry cells?

From this experiment you have learned that the strength of an electromagnet can be increased by increasing the number of turns of wire around the soft iron core or by increasing the current in the wire. As electromagnets are used for different purposes, it is desirable that they vary in strength.

Uses of electromagnets. Electromagnets are used for a great many purposes. They are employed in electric bells, buzzers, telegraph instruments, telephones, and radios. Electromagnets are also used for regulating the distance between the ends of carbon rods in an arc lamp, for unlocking doors in apartment houses, and for many other purposes.

A very interesting use of huge and powerful electromagnets is the electric crane used to unload pig iron and scrap iron in steel plants and to moving large iron castings from place to place. When a casting is to be lifted, the electric current which magnetizes the electromagnet is turned on. The crane then picks up and moves the casting from one place to another. When the current is turned off, the iron core in the electromagnet loses its magnetism and the casting drops off.

Problem: How Is a Powerful Electric Current Generated and How Is It Measured?

How are powerful currents of electricity generated? You have learned that a current of electricity passing through a wire sets up a magnetic field. You will now learn that a magnetic field can be used to produce an electric current.

Experiment 132. To produce an electric current. Connect a coil of several turns of insulated wire with a *galvanometer*, an instrument used to detect the presence of even a feeble electric current (Fig. 275). Thrust one pole of a bar magnet or horseshoe magnet quickly into the coil and observe the galvanometer needle. What happens? When the needle comes to rest, withdraw the magnet quickly; at the same time watch the needle. What happens?

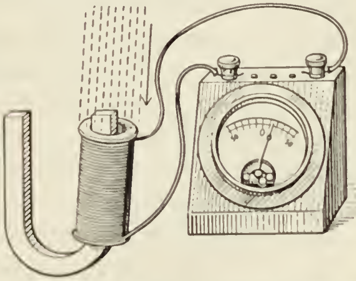


Fig. 275. When the coil is thrust down over one pole of the horseshoe magnet, what happens to the galvanometer needle?

Now, keeping the magnet still, thrust the coil over one pole. What force moved the coil? The magnet? Does the galvanometer needle move? Does the needle move when both coil and magnet are stationary?

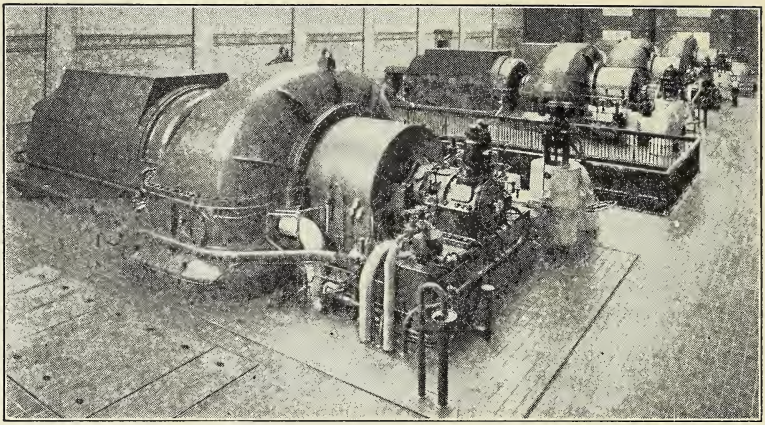


Fig. 276. Each of the machines in this modern plant for generating electricity is a steam-driven generator, capable of producing 50,000 kilowatts.

This experiment shows that a current of electricity is produced if a coil of wire cuts through the magnetic field of a magnet or if the magnetic field of a magnet is made to cut through the coil. It shows also that if neither the coil nor the magnet move, no current is generated. These facts were discovered by Faraday, a famous English scientist, in 1831. Faraday used these facts to invent a machine in which coils of insulated wire cutting through a magnetic field generated electricity. Today we call such a machine a *generator*. The generator (Fig. 276) is now used very extensively to furnish electricity used in the home, to light streets, to run street cars, electric trains, and machinery. What other uses of electricity can you name?

Experiment 132 shows the three essentials for producing an electric current with a generator: (1) a magnetic field, (2) a coil of insulated wire, and (3) a force (power) to move the coil of insulated wire, so that it will cut the lines of force in the magnetic field. Figure 277 is a diagram of a generator showing the arrangement of the magnets and the coil of insulated wire (armature) so that a force can turn the armature in a magnetic field, thus making the armature cut through the magnetic lines of force, which produces current.

To produce electric current for homes in cities and industries, the power to turn the armature is usually supplied by a water turbine, a steam engine, or a steam turbine. The magnetic field is supplied by electromagnets. Generators that are used to produce electric current for commercial uses have several electromagnets that produce a magnetic field through which the armature cuts as it revolves. The armature is wound with many coils of insulated wire. Current is taken from these coils by means of carbon brushes which press against circular pieces of metal attached to the ends of the coils called slip rings or by a commutator. The latter usually consists of a split metal tube, each part of which is known as a *segment*. The segments are insulated from each other and rotate with the armature. Each end of the wire on the armature is fastened to one of the segments. When the armature rotates, an electric current produced in the insulated wire flows to the commutator, and from there through metal brushes into wires which conduct electricity into homes, office buildings, stores, factories, mines, schools, public buildings, and the like.

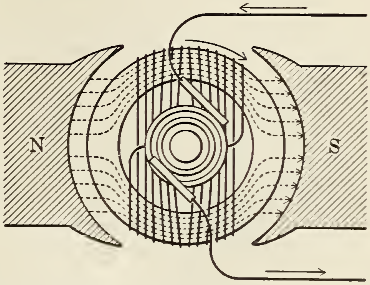


FIG. 277. At what point in its revolution is the coil cutting the greatest number of lines of force?

Electric current produced in this way may be either *direct* or *alternating*, depending upon the construction of the generator. A direct current flows through a conductor steadily and in one direction. An alternating current flows through a conductor first in one direction and then in the opposite direction. This back and forth movement occurs many times a second. Most of the electric current used in homes and industry is alternating current.

What is a transformer? The *transformer* is used in many ways in the transmission and use of electricity. A simple experiment which we will now perform will show you what a transformer is and how it works.

Experiment 133. To make and operate a simple transformer. Set up the apparatus shown in Figure 278. The turns of wire, *M*, are called the primary coil. The turns of wire, *N*, are called the secondary coil. Touch the loose end of wire *A* to the battery terminal *B* and immediately withdraw the wire. When the wire was touched at *B* and withdrawn, what happened to the galvanometer needle at *C*? What did the movement of the needle show?

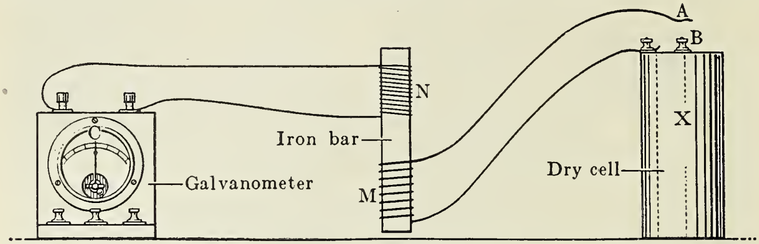


FIG. 278. A step-up transformer. Tell how it works.

Hold wire *A* to the terminal *B* for 30 seconds. Observe the galvanometer needle while the wire is held in contact with *B*.

The fact that the galvanometer needle did not move indicates that a steady direct current in the primary coil will not produce a current in the secondary coil.

In explaining the operation of a transformer you must remember that a wire carrying an electric current produces a magnetic field around it. Also, that when a magnetic field cuts through a coil of insulated wire forming a circuit, a current of electricity is set up in that circuit. When wire *A* touched *B*, what flowed through the primary coil? What was produced in the primary coil? These magnetic lines of force were conducted by the soft iron core through the secondary coil. When these magnetic lines of force cut through the secondary coil, what was set up in it? Why did the galvanometer needle move?

Use a longer wire for the secondary coil and wind more turns of wire around the iron bar and connect it to the galvanometer. Touch the wire *A* to *B* again and observe the movement of the galvanometer needle. How did this movement of the needle compare with the movement of the needle when the secondary coil was made up of fewer turns of wire?

Use a longer wire for the primary coil and wind more turns of wire around the iron bar. Touch wire *A* to *B* again and observe the needle. How does the movement of the needle now compare with its movement when the primary coil was made up of fewer turns of wire?

Connect another dry cell in series and touch wire *A* to *B*. How does the movement of the needle compare with its movement when only one cell was used in the primary circuit?

When an alternating current flows through the primary coil of a transformer the magnetic lines of force are reversed every time the current reverses its direction. This reversing of the magnetic lines of force produces the same effect as making or breaking the circuit when the current is direct. When an alternating current flows through the primary coil of a transformer, an alternating current of higher or lower voltage is set up (induced) in the secondary coil. If the number of turns of wire in the secondary coil is greater than the number of turns of wire in the primary coil, the voltage of the induced current is greater than the voltage of the current in the primary coil. This type of transformer is called a *step-up* transformer.

If the number of turns of wire in the secondary coil is less than the number of turns of wire in the primary coil, the voltage of the induced current is less than the voltage of the current in the primary coil. This type of transformer is called a *step-down* transformer.

If a varying (pulsating) direct current, such as is produced in a telephone transmitter or a radio microphone, is sent through the primary coil of a transformer, an alternating current of higher or lower voltage, depending upon the number of turns in the coil, is induced in the secondary coil.

For what are transformers used? Perhaps you have noticed a sign reading "Danger, High Tension Wires." Such a sign indicates that those particular wires are used to transmit electric energy at high voltage and are more dangerous than others. Electricity which is to be transmitted some distance is conducted as an alternating current of very high voltage—sometimes 132,000 volts or even more. Such high voltages cannot be used safely for electric power in the home. Why? To reduce the voltage, a step-down transformer is used

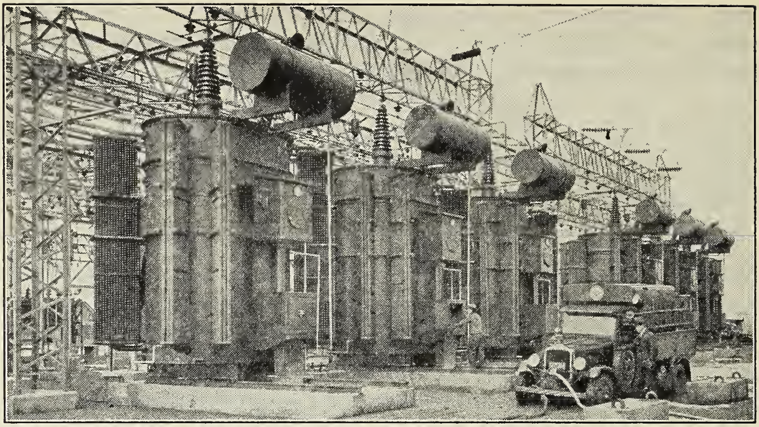


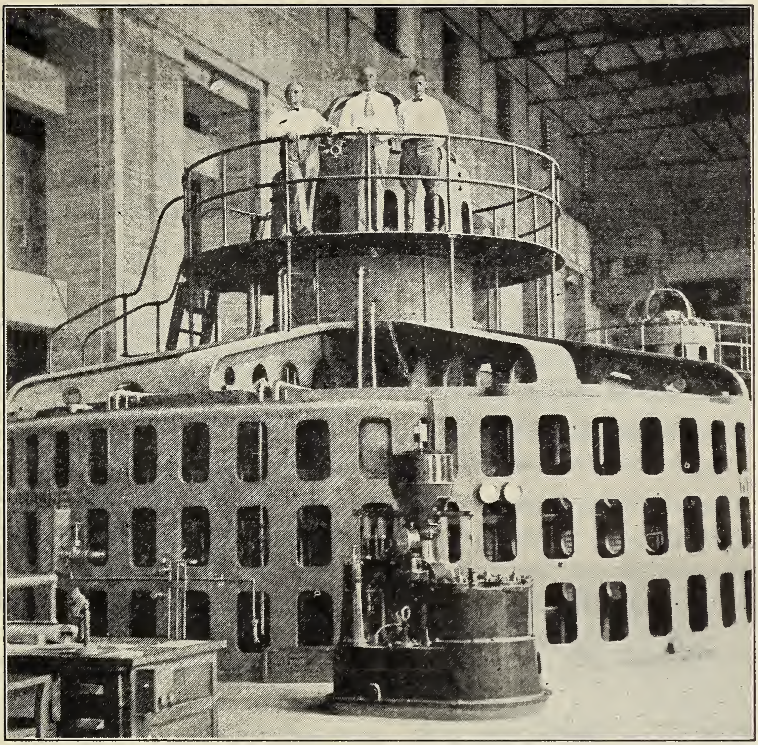
FIG. 279. These transformers step-up the voltage from 13,200 volts to 132,000 volts.

A small step-down transformer is used to reduce the voltage used in homes to the lower voltage needed to operate an electric toy such as an electric train. This toy transformer operates on the same principle as the step-down transformer that reduces the voltage of high tension circuits to the 230 and 115 volts commonly used in homes and in offices.

It is also possible to increase a low voltage by means of a step-up transformer (Fig. 279). In some regions, generators driven by steam turbines produce electricity at 13,200 volts. The voltage is then increased by step-up transformers to 132,000 volts which makes it possible to transmit the current for approximately 130 miles with very little loss of electric energy. A current of 23,000 volts is generated at Niagara Falls and carried twenty miles to Buffalo, where it is reduced to 230 and 115 volts.

The transformer changes a high to a low voltage, or a low to a high voltage.

Water power is used more and more to generate electricity. For many years some of the water power of Niagara Falls has been used for this purpose. On account of the electric power available there, industries such as those which produce carborundum and aluminum have located near the Falls. The United States



Courtesy Chief of Engineers, War Dept.

Fig. 280. Huge generators like this one at Muscle Shoals furnish electricity for industrial and domestic use. This plant was begun during the World War to furnish power for the manufacture of explosives, but is now being used for peace time purposes.

government has built a huge electric plant at Muscle Shoals for the production of electricity for use in that region (Fig. 280); Boulder Dam is another government project which will supply electricity for another section of the country.

How is electric power measured? When electric lamps were first used, the different sizes were measured in terms of candle power. So, when purchasing a bulb for an electric lamp, instead of asking for a 25-watt bulb, or a 50-watt bulb, as we do today, the purchaser asked for a 16-candle power bulb, or a 32-candle power bulb, and so on. But since electricity that comes to our homes is used for purposes other than lighting, it is now measured in terms of power. The unit used to measure electric power is the *watt*, named in honor of James Watt. For large amounts of electric power the *kilowatt* (1000 watts) is used.

The power used in any part of an electric circuit can be found by multiplying the number of amperes of current by the number of volts of electric pressure, that is:

$$\text{Watts} = \text{Amperes} \times \text{volts}$$

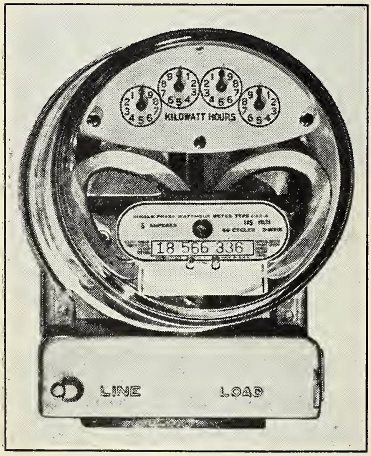
For example, if an electric light bulb uses $\frac{1}{2}$ amperes of current in a 110-volt circuit, it must require $\frac{1}{2} \times 110$ or 55 watts of electric power, and so is a 55-watt bulb.

Special problem. Find the current in amperes required to heat an electric device which uses 600 watts in a 110-volt circuit.

The watt-hour meter. The watt-hour meter is used to measure electricity used in homes, factories, etc. If we wish to determine the total amount of energy used in a given period, we must consider not only the power used but the length of time it is used. Suppose 10 watts of power are used for one hour; then 10 watt-hours of electric energy have been used, that is:

$$10 \text{ watts} \times 1 \text{ hour} = 10 \text{ watt-hours}$$

If 100 watts of electric power were used for 10 hours, then 1000 watt-hours would have been used. Since 1000 watts equal one kilowatt, 1000 watt-hours could be called one kilowatt-hour (abbreviated K.W.H.). A K.W.H. is the unit used to determine the amount of an electric bill.



Courtesy General Electric Co.

FIG. 281. Is the kilowatt-hour meter in your home like this one?

How to read the watt-hour meter. If you examine the electric meter in your home, you will see a disk that revolves when the current is turned on anywhere in the house. This revolving disk is connected by gears to several pointers or hands somewhat like those of a clock (Fig. 281). The readings of the positions of these pointers are in kilowatt-hours.

Figure 282 shows the dials of a meter on two different dates. Notice that the numbers on the dial at the extreme right (the 10-kilowatt dial) start at zero at the top and increase in the direction taken by the hands of a clock, clockwise. The numbers on the 1000 kilowatt dial run the same way. The numbers on the 100 kilowatt dial and on the 10,000 kilowatt dial run counter-clockwise.

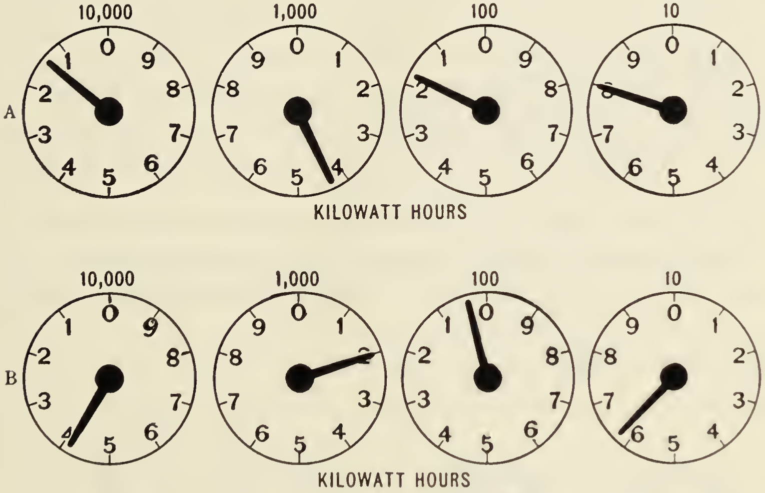


Fig. 282. *A*, the dials of a watt-hour meter in a Massachusetts factory on July 2; *B*, the dials of the same watt-hour meter one month later. How much electricity has the factory used during July?

When a meter is installed, all the pointers are at zero. Now, suppose the meter is attached to a device that uses one kilowatt of power. At the end of one hour the hand on the dial at the extreme right at the top will have moved to figure 1 and at the end of two hours it will have moved to figure 2. When the pointer has traveled once around this dial, the pointer on the second dial will be at figure 1 on that dial, indicating that

10 kilowatt-hours have been used. The third dial shows the hundreds of kilowatt-hours, and the one on the left indicates the thousands. In reading the dials, if the pointer is between two numbers, we read the smaller.

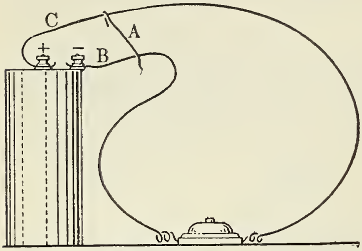


Fig. 283. Explain from this diagram how a short circuit might occur?

In reading the meter on the dates indicated (Fig. 282), first read the dial at the right and put the number down in units' place; put the number on the next dial in tens' place, and so on. If you have not learned to read the watt-hour meter in your home, do so now.

Problem: How Is an Electric Circuit Made Safe?

What is a short circuit? If for any cause, the current in a circuit flows in a shorter circuit or one of less resistance than its regular circuit, it is said to flow in a *short circuit*. Figure 283 shows a short circuit caused by the small wire. A short circuit is

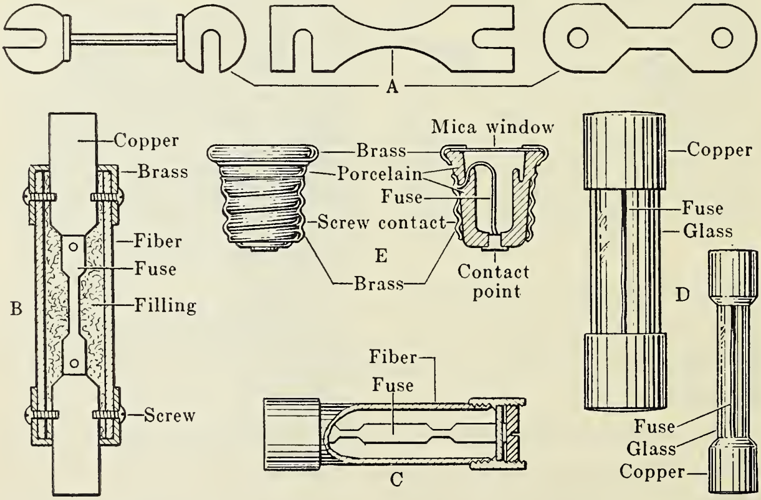


Fig. 284. Different kinds of fuses: *A*, open link; *B*, *C*, and *D*, fuses to be slipped into openings; *E*, the familiar screw plug fuse.

dangerous because it allows such a strong flow of electricity that the wires carrying it may become heated enough to set fire to materials in contact with them.

How fuses prevent damage from short circuits. *Fuses* may be thought of as safety valves. If from any cause, such as a short circuit, more electricity passes through wires that carry a current than they can carry safely, the fuse wire melts. This breaks the circuit and stops the flow of electricity. The breaking of the circuit may be the means of saving a building from fire.

Kinds of fuses. Figure 284 shows a number of different kinds of fuses, some of which you have doubtless seen. The simplest fuse is a plain wire made of an alloy, generally of tin and lead. This alloy melts at a lower temperature than the copper wires of the circuit. The ordinary screw plug fuse is very easy to install and prevents a possible spattering of melted metal when it "blows out." This spattering of melted metal may easily occur when the plain wire fuse or open link fuse is used.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

alternating current
ammeter
ampere
armature
attract
battery
commutator
conductor
direct current
electricity
electrode
electrolyte
electromagnet
electron
fuse
galvanometer
generator
induction
insulator
kilowatt
lines of force
lodestone
magnet
magnetic field
negative charge
negative pole
non-conductor
ohm
cells in parallel
positive charge
positive pole
proton
repel
resistance
cells in series
short circuit
slip ring
transformer
volt
voltaic cell
voltmeter
watt, watt-hour

Write the number of each item on your paper and after it the word that completes the statement.

1. A glass rod rubbed with a silk cloth produces a ________ charge of electricity.

2. Unlike charges of electricity ________ each other.

3. A stream of ________ moving along a conductor is known as an electric current.

4. An electric current produced by a dry cell is generated by ________.

5. The unit used to measure the resistance of an electric circuit is called the ________.

6. The region about a magnet containing magnetic lines of force is called a ________.

7. When magnetic lines of force are cut by a loop of insulated wire an ________ is produced.

Which item in each of the following lists does not belong with the others?

8. conductor; glass; metal; copper; silver.

9. electric current, generator; lightning; magnetic field; electron.

10. high voltage; transformer; alternating current; direct current; low voltage.

Which of these statements are true? If any are false, re-state them in correct form.

11. Like charges of electricity attract each other.

12. A dry cell changes mechanical energy into electrical energy.

13. A conductor transmitting an electric current sets up a magnetic field about the conductor.

14. Copper can be magnetized easily.

15. Every electrical generator must have a magnetic field.

16. The formula for calculating amperes is $A = V \times O$.

17. Conductors do not offer resistance to the flow of electricity.

CHAPTER XXIV

HOW IS ELECTRICITY USED IN HOME AND INDUSTRY?

Do you know:

What makes an electric motor run? That it is possible for you to construct a simple electric motor? That the highest temperature on the earth's surface is produced by electricity? What the best conductor of electricity is? What substance offers the greatest resistance to electricity? That some precious stones such as diamonds can be made in an electric furnace?

That electricity can be used to break down water into two gases? That copper is refined by means of electricity? That the printing of this book depended upon electricity? What an X-ray is? That stolen goods have been located by using X-rays? That a person may be seriously injured or killed by the electric lighting circuit in the home?

PROBLEM: HOW IS ELECTRICITY USED TO RUN A MOTOR?

What are the uses of electricity? The use of electricity has changed the ways of living of many people. In the home electricity is used to provide heat and light; to heat toasters, percolators and irons; to run vacuum cleaners, washing machines and electric refrigerators. How many other electric appliances can you name that are used in the home? You can see that in a home equipped with such appliances, electricity does the work of many persons.

If to the work electricity does in the home you add the work it does in industry, transportation, and communication, you cannot help but realize what a powerful servant we have in this great source of power. If you will count the number of times each day you make use of electricity or of some product produced by the use of electric power, you will be aware of the many ways in which our lives are changed by its use.

What makes an electric motor run? In Experiment 124, you observed that like poles of magnets repel each other and unlike poles attract each other. In Experiment 128 you learned that a current of electricity in a wire sets up a magnetic field (about the wire) which will cause a compass needle to move. This movement is due to magnetic forces of attraction and repulsion which are the same as those you observed between the poles of magnets. An electric motor is a machine constructed so that magnetic forces of attraction and repulsion are used to produce a continuous rotary motion. The following experiment will show the construction and operation of a simple motor. The more complex electric motor used in industry operates on exactly the same principle.

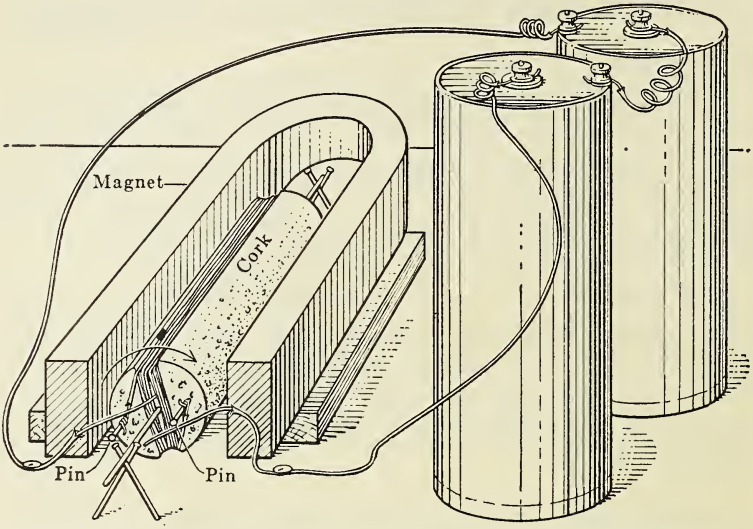


FIG. 285. All electric motors are built on the same principle as this simple one.

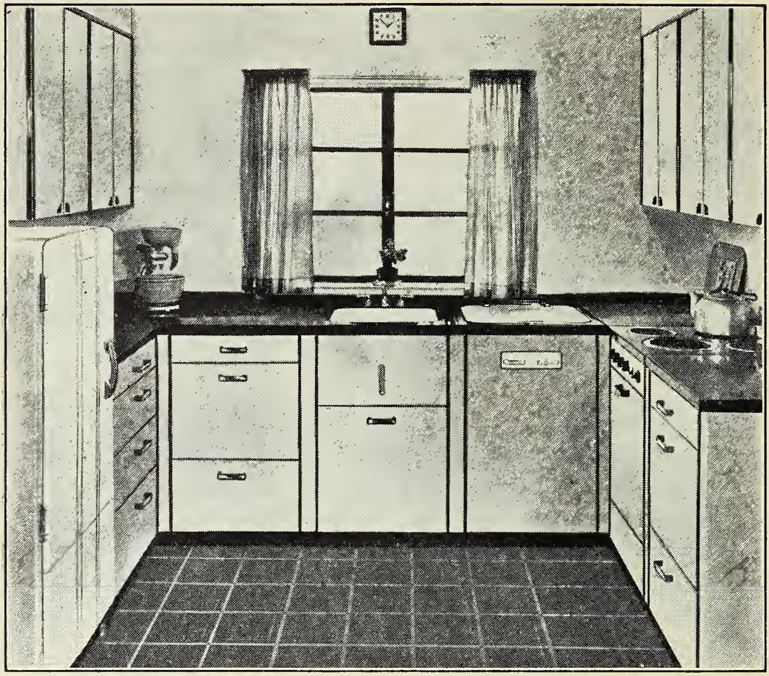
Experiment 134. To construct a simple electric motor. Procure a cylindrical cork about two inches long and about one inch in diameter. Cut notches lengthwise on opposite sides of the cork (Fig. 285) and wind 25 or 30 turns of insulated wire (size No. 20 or 22) in the notches. Now push two straight pins, preferably brass, into one end of the cork, placing them at right angles to the coil of wire and allowing them to extend about one quarter of an inch from the cork. Fasten the free ends of the wire to these two pins, one end to each pin. Now place another pin in the center of each end of the cork to form a shaft for the motor. Also, arrange pins, as shown in the diagram, and place the cork with the shaft in them so it may rotate. Place one or two horseshoe magnets around the cork as shown in the diagram. Connect two dry cells in series and bring a wire from each pole of the battery to furnish the electric power. Remove the insulation from two inches of the free ends of the wires from the battery and bring them in a horizontal position into contact with the two pins in the cork to which the wires of the coil are attached. The cork should revolve rapidly. If it does not, a little experimenting will produce the desired result. Reverse the direction of the current and note the results.

This simple motor shows the essential parts and operation of an electric motor; (1) the horseshoe magnet supplies a magnetic field; (2) the coil of insulated wire wound on the cork and mounted so that it is free to rotate is the armature; and (3) the electric current from the dry cells supplies the power which causes the armature to turn in the magnetic field. The ends of the wire from the dry cells serve as brushes which conduct the current to the commutator. In this simple motor the commutator is the two brass pins to which the ends of the armature coil are fastened.

Notice that a motor and a generator have the same parts. In fact the same machine may be used either as a motor or a generator. In the generator, the energy which causes the armature to rotate is transformed into the electric energy of the current produced. In the motor, the electric current causes the armature to rotate, thus changing electric energy into a form of energy which can be used to turn the wheels of machinery.

Experiment 135. To study the construction and operation of a toy motor which may be used to do work. Study the construction of a toy electric motor to find (1) the magnet, either a permanent magnet or an electromagnet; (2) the armature; (3) the commutator; (4) the brushes.

Connect the toy motor in a circuit with a dry cell. What happens? If the magnetic field in the motor is produced by an electromagnet trace the wiring of the magnet and observe how some of the electric current from the dry cell is conducted through the electromagnet. Are the electromagnet and the armature connected in series or in parallel?



Courtesy General Electric Co.

FIG. 286. How many electric appliances do you see in this picture?

How does the electric motor serve us in the home? If you will examine common household electric appliances, you will find that many of them are run by power furnished by an electric motor. This is true of the electric washing machine, vacuum cleaner, sewing machine, and refrigerator. What others can you name?

The electric motor is one of the most reliable sources of power. For example, in an electric refrigerator, a motor which is properly constructed and well lubricated runs for months without attention. You have probably observed that the motor in an electric washing machine or a sewing machine is always ready for service if given the little attention which it requires. The touch of a button or switch turns on the power needed to operate these machines. As we discover further uses for it the electric motor will serve us more and more in the home.

How does the electric motor serve man in industry? The electric motor is used so widely in industry that only a few uses can be mentioned. Have you ever noticed that when an automobile is driven up to the doors of certain public garages the doors open almost mysteriously? If you knew how the doors operated there would be no mystery because they were opened by an electric motor started by the pressure of the car on a concealed switch. Electric motors are used in garages and factories to run machines of many kinds. On farms electric motors are used to pump water and run small machines (Fig. 286). In an office building they are used to run elevators, to pump water, to run fans that force air through the building to keep it at a comfortable temperature. What other uses of the electric motor in buildings, factories and elsewhere can you mention?

The use of the electric motor in transportation will be treated in the next chapter.

PROBLEM: HOW IS ELECTRICITY USED TO PRODUCE HEAT AND LIGHT?

How is electricity used for heating purposes? An electric toaster is a good example of devices that use electricity to produce heat. When a toaster is in use, an electric current causes the wires to be heated until they are red hot. The amount of heat produced depends upon the resistance of the wire and the current flowing through it.

Experiment 136. To show the heating of a wire with electricity. Connect the terminals of a dry cell with one foot of No. 30 copper wire. Does the temperature of the wire increase as the current is flowing through it? Now connect a foot of No. 16 copper wire in series with the No. 30 wire. Which wire becomes the hotter? Does the heat generated in a wire depend on the diameter of that wire?

Connect the terminals of a dry cell using No. 30 iron wire, connected in series with No. 30 copper wire. Did the iron or the copper wire become more highly heated? Does the heat generated in a wire depend upon the material of which it is made?

The heating effects of electricity. Experiment 136 shows that a current of electricity in a wire generates heat and that the heat generated varies with the size of the wire and the material of which it is made. You already know that a wire offers resistance to the flow of a current through it. It is believed that as the electric energy overcomes this resistance, some of it is changed into heat energy.

If the same current of electricity is forced through two different wires of the same length, the larger part of its kinetic energy is changed to heat in the wire which offers the greater resistance. Consequently metals to be used in the heating element of an electric appliance should have a fairly high resistance to the flow of electricity. They also need to have a high melting point. Why? Scientists have developed two alloys, nichrome and manganin, which meet these requirements.

As silver offers less resistance to the flow of an electric current than any other metal, it is the best metallic conductor of electricity that we know. Would you expect much or little heat to be generated when a current flows through a silver wire? Why?

In a list of resistances offered by metals to the flow of an electric current silver stands at the foot as shown:

Silver	1.00	Soft iron	10.00
Copper	1.11	Hard steel	13.50
Aluminum	1.87	Nichrome (alloy)	63.00
Tungsten	3.00	Manganin (alloy)	170.00

For carrying electric currents long distances would wires of nichrome be used? Explain.

Special problem. Have the members of the class bring in electric appliances such as a toaster, an electric heater, or a flatiron. Show how each operates and explain its operation in terms of amount of current used and resistance to the current in the heating element.

How is the heating effect of electricity used in the home and industry? If you were to enumerate the electric heating appliances used in a home, you would be thoroughly convinced that electricity is man's greatest servant. You have learned already that the heating effect of electricity used in the incandescent bulb has revolutionized the methods of lighting homes, office buildings, factories, and streets of cities. Electricity used to produce heat

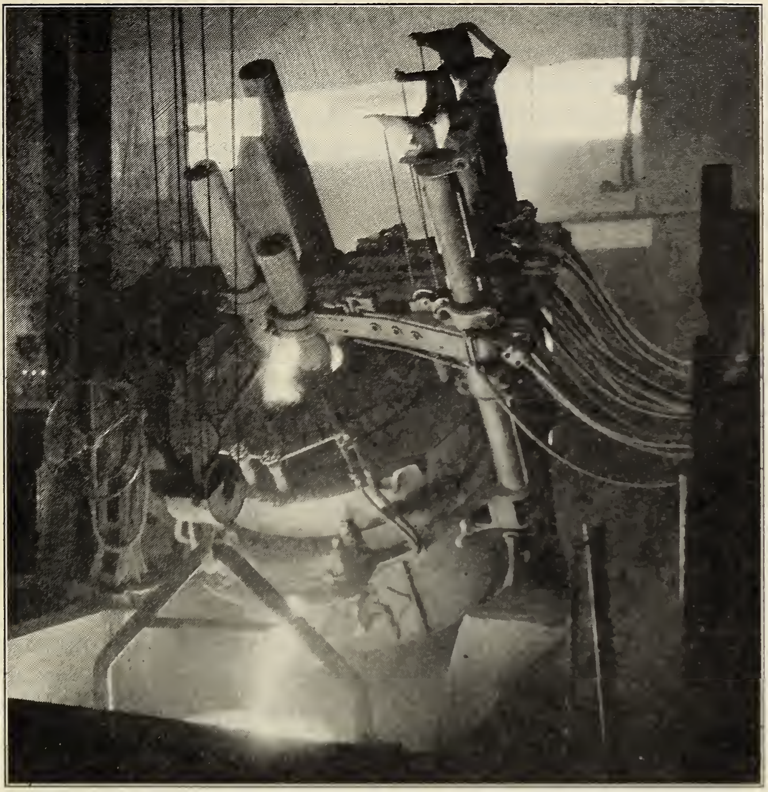


FIG. 287. In electric arc furnaces of this type many alloys can be made because of the intense heat. This furnace is being tipped to allow the molten metal to flow out.

for other uses has caused almost as great a change. Some of the electric appliances that produce heat in the home are the stove, toaster, heater, flatiron, and percolator. What other appliances can you add to this list?

In industry the electric furnace is producing new wonders almost daily because in an electric furnace higher temperatures (about 7000° F.) can be obtained than in any other furnace (Fig. 287). The electric furnace has made possible the cheap production of aluminum and its many alloys and also the manufacture of carborundum, a hard substance used for smoothing castings and sharpening tools. Some kinds of high grade steel can be produced best in an electric furnace. Because of the very high temperature of the electric furnace some kinds of precious stones can be made in it. Artificial diamonds have been made but as yet the process is not sufficiently perfected to make their production a commercial success.

Electricity is used in greenhouses to supply heat to germinating seeds and growing plants from a heating element buried in the soil a few inches below them. The electric current is so controlled that the temperature most suitable for growth is maintained. Young plants whose growth is aided in this way are larger and have a better root growth (Fig. 288). Undoubtedly, more and more electricity will be used for this purpose in the future.

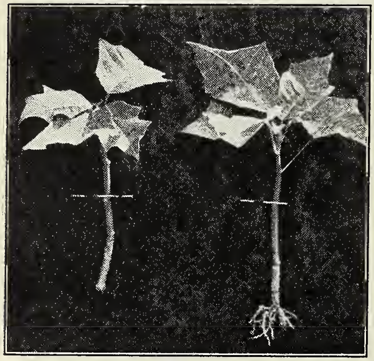


FIG. 288. The plants are of the same age, but the soil around the roots of the plant on the right was warmed by electricity.

How is the heating effect of electricity used to produce an electric arc? The following experiment will show how electricity is used to produce the brilliant light of the electric arc.

Experiment 137. To make an electric arc. (Teacher's experiment.) Procure two carbon rods (the carbon rods from two worn-out dry cells will do) and make a point on one end of each with a file or emery wheel. Fasten the rods to a wooden or metal frame something like that in the diagram (Fig. 289). Attach a No. 18 copper wire to each carbon rod. If a 115-volt lighting circuit is used, a suitable resistance (rheostat) should be connected in the circuit.

One rod should be free to move back and forth, making it possible to make the point of the movable rod touch the point of the other rod and to withdraw it a short distance. If the rod is moved with the hand, it is advisable to cover the end of the rod with friction tape or to wear a rubber glove. Why? Separate the rods about an inch and connect the wires with the lighting circuit. After the current is turned on, push the points of the carbon rods together, and then pull them apart about a quarter of an inch. As the rods are separated an arc will be produced. Do not look directly at the arc for any length of time, as its bright light is injurious.

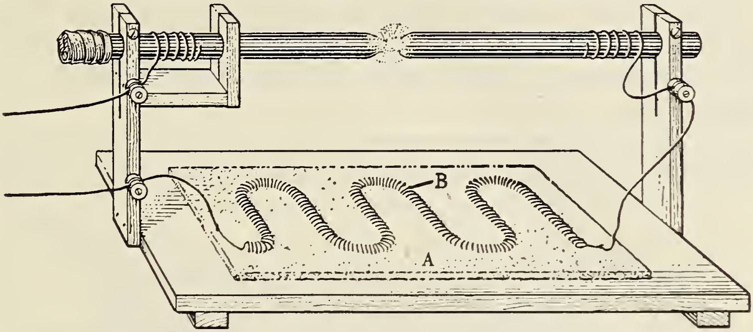


FIG. 289. A home made arc lamp. *B*, a rheostat or a wire that offers a suitable resistance. *A*, an asbestos pad. Why is it used?

When the carbon rods touch after the current is turned on, a very high temperature, about 7000° F., is produced. This heat vaporizes the carbon at the point where the rods touch, and when the rods are pulled apart, the vaporized carbon becomes incandescent as it conducts the electricity between the rods. Because of its brilliant light, the electric arc (Fig. 290) is used in moving picture machines and other projectors.

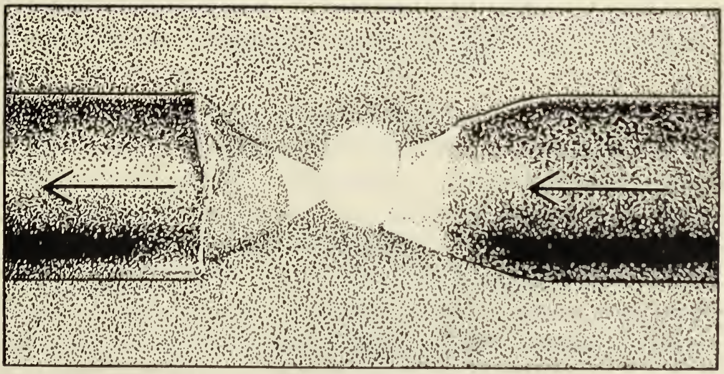


FIG. 290. The ends of two carbon rods with an electric arc between them. Notice that one rod is cone shaped, the other blunt.

PROBLEM: HOW IS ELECTRICITY USED TO PRODUCE CHEMICAL CHANGES?

When a direct current of electricity was passed through water, page 85, into what two elements was the water decomposed? In much the same way other chemical changes may be caused by a direct current.

How is a direct current of electricity used in electroplating silver? Figure 291 is a diagram of the apparatus used to electroplate silver. The tank is partially filled with a solution in which the electrolyte is a compound containing silver. Both the electrodes (poles) must be immersed in the solution. The objects to be plated, such as spoons, are attached to the negative pole and a bar of pure silver is attached to the positive pole.

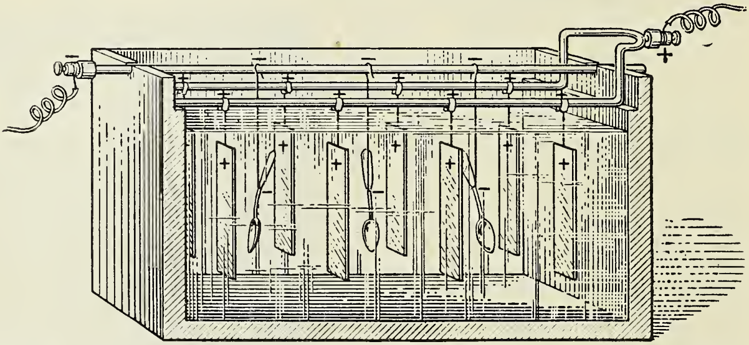


FIG. 291. Suggest a reason why in an electroplating tank bars of silver and spoons are alternated.

If you were to examine the spoons a few minutes after the current was turned on, you would find a layer of silver had been deposited on them. The current causes some of the pure silver from the bar to be dissolved in the solution. At the same time some of the silver in the solution leaves the solution and is deposited on the spoons, or as we say, the spoons are silverplated. The process of plating a metal by the use of electricity is called *electroplating*.

The same process is used in electroplating certain automobile parts and many other objects with chromium, cadmium, nickel, and the like.

How is a direct current of electricity used in refining copper? Copper for commercial uses is refined in much the same way as spoons are plated with silver. Copper bars that contain impurities are attached to the positive pole and immersed in a tank containing a solution of copper sulfate. Very thin sheets of pure copper are attached to the negative pole and immersed in the solution. When the current of electricity is turned on, the copper bars dissolve slowly in the solution from which pure copper is deposited on the thin sheets of pure copper. The impurities from the dissolved copper bars either remain in the solution or sink to the bottom of the tank. Commercial copper refined in this way is about 99 per cent pure. How many pounds of pure copper would there be in 200 pounds of copper 99 per cent pure?

How is a direct current of electricity used in electrotyping? Very few books are printed directly from type. The words on a page of a book are first set up in type, and an impression made in wax or gutta-percha. This impression, called a mold, is then carefully dusted with a thin coat of graphite (carbon), a good conductor of electricity. The graphite-covered mold is then made the negative pole in an electroplating tank; a plate or bar of pure copper is used as the positive pole; and a solution of copper sulfate as the electrolyte. A direct current of electricity is turned on until a coating of copper has been deposited on the graphite-covered mold. The mold with the attached copper shell is removed from the tank. After the copper shell has been separated from the mold, it is backed with an alloy of lead, making the plate strong enough to be used in printing. This process of using electricity to make a printing plate from type is called *electrotyping;* and the finished plate is known as an electrotype.

The storage battery. The storage battery is a necessary part of the equipment on nearly all forms of modern transportation whether highway, rail, water, or air, and of modern communication, whether radio, telephone, or telegraph. In rural districts, storage batteries may be charged by making use of windmills.

The common lead storage battery consists of two or more cells connected in series. Each cell contains two sets of plates; one set is positive and one set is negative. The framework of a plate is cast from an alloy composed chiefly of lead. This framework consists of small squares or rectangular depressions somewhat like those shown in Figure 292. The depressions of the positive plates are filled with a paste consisting of peroxide of lead, dark brown in color. The depressions of the negative plates are filled with porous spongy lead, gray in color. In each of the cells the positive plates and negative plates dovetail into each other; the plates being prevented from touching one another by thin sheets of insulating material, usually wood or rubber. This arrangement of positive and negative plates is called an "element," or unit. When an element is placed in a solution of sulfuric acid and water, and the top sealed with pitch, the cell is ready for use.

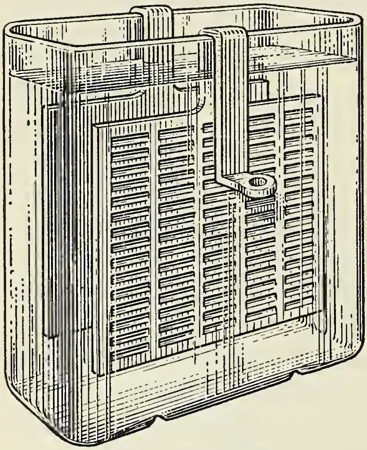


FIG. 292. A lead storage cell.

The cells of a storage battery can be charged by forcing a direct current of electricity through them. This flow of electricity causes a chemical change to take place between the sulfuric acid and the plates, thereby storing up chemical energy. This energy is released again by chemical action when the battery is used to produce electricity.

When a storage battery is discharging, part of the sulfuric acid is used up, thus causing the solution to become more dilute, i.e., less concentrated. When a storage battery is being charged, sulfuric acid is formed again, making the solution stronger, that is, more concentrated. The condition of a battery in respect to its charge can be determined by finding the strength of the sulfuric acid solution. This is done by an instrument known as an *hydrometer*. An hydrometer measures the specific gravity (see page 110) of a solution. In a fully charged battery the specific gravity of the solution is between 1.275 and 1.300.

The storage battery is used in an automobile to furnish the electric power needed to start the motor, and to operate the spark plugs, the lights, the horn, etc. Such a battery is commonly made up of three cells. Each cell, when fully charged, has a voltage of about two volts. Since the plates are close together, there is little resistance within the cells and therefore a large amount of current can be taken from the battery. The storage battery in an automobile is re-charged by a generator attached to the motor.

From forty to fifty such cells connected in series are used to propel small electric trucks such as the baggage trucks used in railroad stations. From sixteen to eighteen cells connected in series are used to furnish electric current for country homes; they usually are charged by a small generator run by a gasoline motor or by wind power.

Problem: How Is Electricity Used to Produce X-Rays?

What is an X-ray? The flow of electricity through a vacuum tube made possible another wonderful and useful invention. In 1895 Röntgen discovered that if a stream of electrons struck upon a hard metallic surface in a vacuum tube rays much more penetrating than light rays were given off from the metallic surface. It is thought that the atoms of the metal are set into vibration by the impact of the electrons and give off these rays. They are much shorter than light rays and penetrate such substances as wood, paper, and flesh. Because Röntgen did not know what these rays were, he called them X-rays. A tube which is designed to produce X-rays is called an X-ray tube.

In what ways are X-rays useful? Dentists use these rays to detect decayed and diseased teeth. X-rays are also useful in treating cancer and some skin disorders. Photographs taken by the use of these rays show fractured bones, Figure 293. By the use of X-rays doctors are able to not only set fractured bones more accurately but also to watch the repair of the bones after they have been set. The use of X-rays makes it possible to

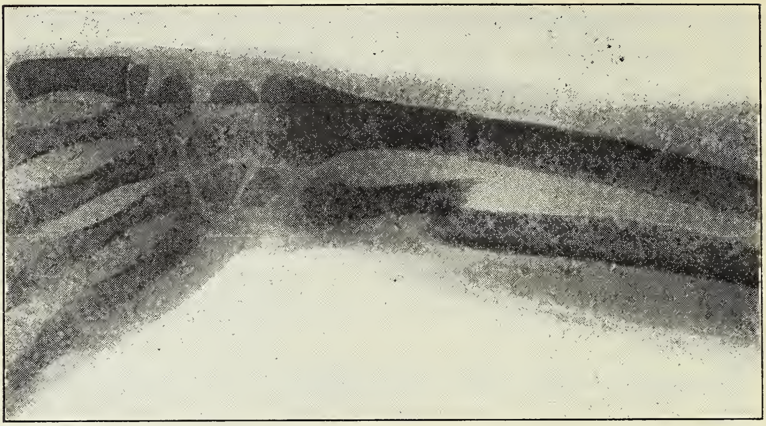


Fig. 293. What does this X-ray photograph show? Of what use are such photographs?

examine the interior of organs of the body. Doctors use X-rays to locate obstructions in the digestive tract and metallic substances which may have entered the body. Many children owe their lives to the use of X-rays in locating pins and other substances in the bronchial tubes and stomach.

In industry X-rays are used to locate blow holes and imperfections in castings. Walls of buildings are sometimes photographed with X-rays to locate hidden articles or reveal structural weaknesses. Stolen goods are sometimes found by X-ray photographs when other forms of search are impossible. More uses for these rays are being found continually in our modern industrial life.

Problem: How Can We Avoid Injury From Electricity?

How may electricity affect our bodies? A newspaper reported recently that a boy who turned on an electric light when in a bath tub was knocked unconscious by the current and died shortly afterward. Another newspaper article told how a school boy was badly burned because the damp string of his kite came into contact with a "live" wire. These accounts and others familiar to you emphasize the need of taking precautions when handling or coming into contact with household electric apparatus, even those using low voltage. You may have heard persons scoff at the idea that the 115-volt circuit in the home may be dangerous; but the danger is there just the same. The bodies of some persons cannot stand as much current, without injury, as others.

The following precautions will help to prevent accidents due to electricity:

(1) Do not attempt to repair or adjust any electric apparatus without detaching it from the electric circuit. Why?
(2) Do not touch at the same time two electric appliances that are connected in the same electric circuit or in different ones. Why?
(3) Do not touch an electric wire or fixture while you are in contact with the sink, stove, laundry tub, bath tub, gas lamp, or anything connected by metal with the ground. Why?
(4) Do not touch an electric lamp or other appliance, when it is connected in a circuit, with damp hands or with a damp cloth. Why?

A safe rule to follow is not to touch any wire, because it may be carrying a high voltage current of electricity. In subways or along railroad tracks, where the third rail system is used, the danger lies in touching the third rail which carries current at a high voltage. A loose wire that is dangling from a pole or lying across a street may be dangerous, for it may be connected with a high tension wire. Should you discover a wire down in the street, notify a policeman at once.

When a person's body comes into direct contact with a high voltage current his nervous system is shocked and his muscles contract. This usually renders him helpless. As long as a person is in contact with a current, do not touch him with your bare hands, for the current may pass through your body. Protect your hands with a silk cloth or several folds of dry newspaper before attempting to rescue him. To stand on a dry board would help to insulate you from the ground and thus break the circuit. If the victim is unconscious when rescued from the current, his clothing should be loosened and his body rubbed to stimulate his circulation. It may be necessary to resort to artificial respiration just as in a case of drowning. Burns caused by electricity should have prompt medical attention.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

cadmium
chromium
copper sulfate
electric arc
electric motor
electroplating
electrotyping
hydrometer
insulated
manganin
nichrome
peroxide of lead
spongy lead
storage battery
X-ray

Write the number of each item on your paper and after it the word that completes the statement.

1. The metal which offers the least resistance to the flow of electricity is __________.

2. The resistance of a metallic conductor such as a wire depends upon its __________ and the material of which it is made.

3. An alloy which has very high electric resistance is __________.

4. A toaster, percolator, and flatiron use the __________ effect of electricity.

5. In an electric arc the electricity is conducted between the carbon rods by __________.

6. In electroplating a __________ current of electricity is used.

7. In electrolysis __________ changes are produced by electricity.

8. In electrolysis the positive and negative poles are called __________.

9. In a storage battery the liquid used is a solution of water and __________.

Which item in each of the following lists does not belong with the others?

10. storage battery; peroxide of lead; spongy lead; direct current; sulfuric acid; dry cell.

11. X-rays; light rays; metallic surface; vacuum tube; bones; electrons.

12. motor; commutator; toaster; brushes; armature.

Which of these statements are true? If any are false, re-state them in correct form.

13. By means of a motor, electric energy is used to produce heat.

14. When a storage battery is charged, chemical energy is changed into electric energy.

15. Wood is transparent to X-rays.

CHAPTER XXV

HOW IS ELECTRICITY USED IN COMMUNICATION AND TRANSPORTATION?

Do you know:

That today communication is carried on largely by electricity? How a telegraph system depends upon the use of an electromagnet? That electricity and not sound flows in telephone wires? That the usual telephone conversation depends in part upon carbon particles? What electric device causes the metal disk in a telephone receiver to vibrate?

That radio tubes are vacuum tubes? What flows from the filament to the plate in a radio tube? Why the filament of a radio tube is heated? That radio waves may be several miles long? That a radio wave can circle the earth at the equator seven times in a second? That in radio broadcasting, electric waves and not sound waves travel through space? That radio performers may be several miles from the broadcasting station and studio?

PROBLEM: HOW IS ELECTRICITY USED TO RING A DOOR BELL?

One of the ever present problems of civilization has been the problem of communication. The first messenger doubtless was a man on foot. Later, messengers rode on horses. You have read about the ride of Paul Revere, and probably also about the Pony Express and the riders who carried the mail to villages and settlements in the early days of our country. Man has trained carrier pigeons to act as messengers. Carrier pigeons are a necessary part of the communication system of an army. Many times pigeons have carried messages through battle lines when other means of communication failed.

Very early in the history of civilization men learned to communicate with one another by means of signals. Primitive man used signal fires. Probably you have read how Indians signaled with smoke and fire. By means of a blanket the smoke was sent up in puffs, which had a meaning. In our time men communicate with one another by flags during daylight. Boy Scouts learn this means of communication. Flash lamps can be used when it is dark. If weather conditions make the use of flags and flashing lamps impossible, sounds are used. For example, a fog horn is used as a signal to ships.

What are some of the electric devices used for communication? With the development of science in the nineteenth century men began to use mechanical devices to communicate with others at a distance. Today communication is carried on largely by means of electric devices, the electric door bell, telegraph, telephone, radio and the like.

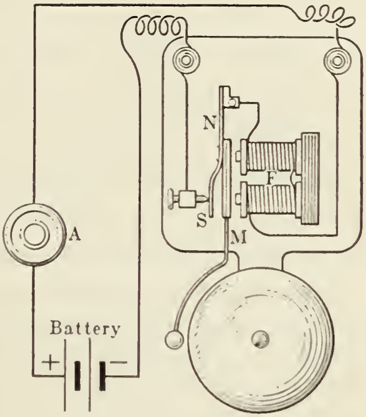


Fig. 294. Explain how this electric bell is operated by the battery.

Experiment 138. To study the operation of an electric door bell. Connect an electric bell in series with two dry cells and a push button (switch) *A* (Fig. 294). Remove the metal cover of the bell to expose the coils. Trace the flow of the current from the battery along the wire, through the closed switch, through the bell, and along the wire back to the battery again. What happens when you press the push button?

When you press the push button, the circuit is closed at *A*. The current now passes through the coils at *F*, making an electromagnet. The magnet attracts the strip of metal *M* to which the hammer is attached. When the hammer is drawn sufficiently near the magnet, it strikes the bell. But this movement of the hammer breaks the circuit at *S*, and the coils immediately lose their magnetism, that is, are demagnetized. The hammer is now thrown back by the spring *N*, which attaches it to the framework of the bell, thus closing the circuit again.

So rapidly does this closing and opening of the circuit take place that the hammer will produce a buzzing noise if the bell is removed. Buzzers are often used instead of bells to communicate from one room of a building to another.

PROBLEM: HOW IS ELECTRICITY USED TO COMMUNICATE BY TELEGRAPH AND TELEPHONE?

Who invented the telegraph? People in the United States, when asked who invented the telegraph, usually say Samuel F. B. Morse. While it is true that the improved instruments used today resulted directly from his invention, there were two men in England, William Cooke and Charles Wheatstone, who also applied for a patent on a telegraph instrument in 1835, the same year that Morse applied for his. As has happened frequently in the growth of scientific discoveries and inventions, scientists in different countries, often quite unknown to each other, have worked on the same problems and have made the same discoveries at just about the same time.

Experiment 139. To show the operation of a simple telegraph system. Connect a telegraph *key* and *sounder* in series with a dry cell. Close the circuit by pressing the key. What happens? Press the key several times, thus opening and closing the circuit. What makes the click or sound? What electric device attracts and then releases the iron bar? Beginning with one pole of the dry cell trace the current through the circuit to the other pole. What flows through the circuit, sound or electricity?

In the operation of a telegraph system the operator closes the circuit by pressing down key *K* (Fig. 295). The electromagnet *A* attracts the sounder bar *B* and holds it down as long as the circuit is closed. When the key is raised by the operator, the circuit is broken and the sounder bar is pulled away from the magnet by a spring at *C*. The sound produced by a short closing of the key is called a *dot*, by a longer closing, a *dash*. A certain combination of dots and dashes stands for a letter of the alphabet. Operators learn to read messages by interpreting the clicks made by the sounder bar.

Looking again at Figure 295, you will observe that the two stations between which messages are sent are connected by just one wire. At each station another wire is grounded to complete the circuit. How do these grounded wires complete the circuit? If a message is sent to a distant station, however, the current may not be powerful enough to operate its sounder bar. Consequently an instrument (Fig. 296) called a *relay* is installed instead of a sounder in the main circuit between the stations. At the distant station a local circuit, made up of a battery and a sounder, is attached to the relay. When the key is pressed down at the sending station the current which flows to the distant station passes through the coil of the relay, thus making an electromagnet. The bar in the relay is made very light, so that it is easily moved. When the bar is pulled toward the coil of the relay, it closes the local circuit of the receiving station. The current in the local circuit then operates the sounder, just as the sounder was operated in Experiment 139.

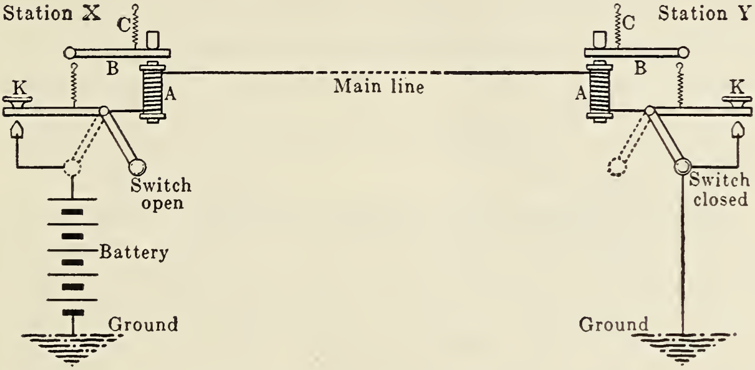


Fig. 295. Explain why only one wire is needed for the main line in a telegraph system like this one.

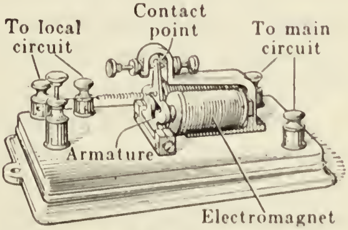


Fig. 296. A telegraph relay which closes and opens the local telegraph circuit.

What are telegraph codes? We have explained how dots and dashes standing for letters of the alphabet can be transmitted by telegraph. Dots and dashes are also used in wireless telegraphy. The systems of dots and dashes used are referred to as *codes.* There are two principal codes in use today. The American Morse Code is used by telegraph operators for messages sent over wires in our country. A modification of this code used by wireless operators is called the International Morse, or the Continental Code. These codes may be found in any encyclopaedia, or Boy Scout Manual.

The use of telegraph and telephone systems. Today the telegraph is extensively used in our country. Stock market prices and weather reports are telegraphed over the United States, Canada and elsewhere. Business messages as well as personal ones are telegraphed daily in great numbers. As long as wireless messages must be broadcast the telegraph will be used for sending private messages. Today, by means of telegraph lines on land and lines carried in cables on the bottom of the ocean, we may communicate with almost any place of commercial or political importance. In the United States alone, there are more than 2,000,000 miles of telegraph lines over which about 215,000,000 messages are transmitted each year.

The telephone is used even more than the telegraph. According to accurate estimates, there are more than 18,000,000 telephones in use in the United States and in general the number is increasing. These telephones are used in more than 27,800,000,000 conversations each year.

Who invented the telephone? In 1875 Alexander Graham Bell demonstrated to the world that vibrations caused by the sound of the human voice could be transmitted by electricity. This was the beginning of the telephone. We do not, however, send sound over wires; when we speak into a telephone transmitter the voice produces sound waves that cause a varying electric current to flow through the wire in such a way as to cause the receiver at the other end of the wire to translate the electric energy back into sound waves that reproduce the voice of the speaker (Fig. 297).

Procure an old telephone *receiver*. Unscrew the end and observe the metal disk (*diaphragm*) held in place by a U-shaped permanent magnet. The ends of this magnet are wound with many turns of fine wire. This U-shaped permanent magnet sets up a permanent magnetic field and the coils of wire set up an electromagnetic field when the circuit is closed. As the strength of this electromagnet varies as the strength of the current changes, it causes the disk to vibrate. The current which flows through the electromagnet is an alternating current. When the current flows in a certain direction in the coil the magnetic field (the sum of the magnetic fields of the U-shaped magnet and the electromagnet) acting on the disk is strengthened and the disk is pulled toward the magnet. When the current flows in the opposite direction in the coil, the magnetic field is weakened and the disk moves away from the magnet. This back and forth movement of the disk sets up sound waves which can be heard.

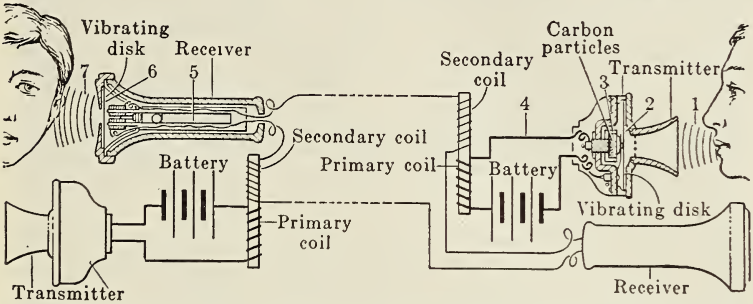
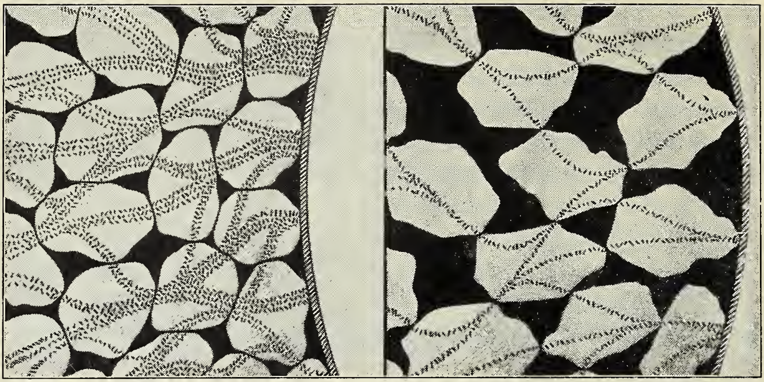


FIG. 297. Explain what happens in this telephone system at points 1, 2, 3, 4, 5, 6, and 7. Notice that there is a battery at each end.

The part of the telephone through which we speak is called the *transmitter*. Like the receiver it has a diaphragm. This diaphragm is so placed that when it is caused to vibrate by sound waves, it presses against small carbon particles packed in a little box. When the diaphragm is forced toward the box (Fig. 298) these carbon particles are pushed closer together; this packed condition of the carbon particles decreases the resistance to the passage of a current and thus causes a larger current to flow through the circuit. Why? When the diaphragm moves back

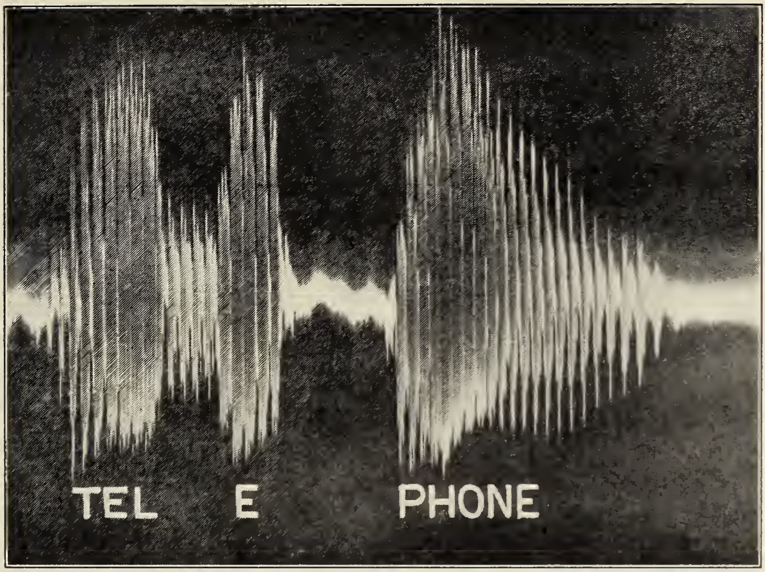


Courtesy American Telephone and Telegraph Co.

Fig. 298. The diagram at the left shows the increased flow of electricity when the carbon particles in a telephone transmitter are compressed. The one at the right shows the decreased flow of electricity when the carbon particles are not compressed.

and away from the box, the carbon particles are not so close together. This condition of the carbon particles increases the resistance to the passage of a current and thus causes a smaller current to flow through the circuit. Why? These movements of the disk take place many times a second, and set up a varying current in the telephone circuit.

Sending a telephone message. When you speak into the mouthpiece of a transmitter the sound waves produced by your voice travel through the air to the diaphragm, causing it to vibrate the same number of times per second as the sound waves produced by your voice. The electric current flowing through the transmitter varies (Fig. 299) as the metal disk moves toward or away from the carbon particles, consequently a varying current is set up in the transmitter circuit. You will notice (Fig. 297) that the transmitter circuit is connected with the telephone circuit by a small step-up transformer. The transformer changes the varying current in the transmitter circuit into an alternating current in the telephone circuit which by varying in the same way as the current in the transmitter circuit causes the metal disk of the receiver at a distant station to vibrate in the same way as the diaphragm of the transmitter. Thus the sound waves of your



Courtesy American Telephone and Telegraph Co.

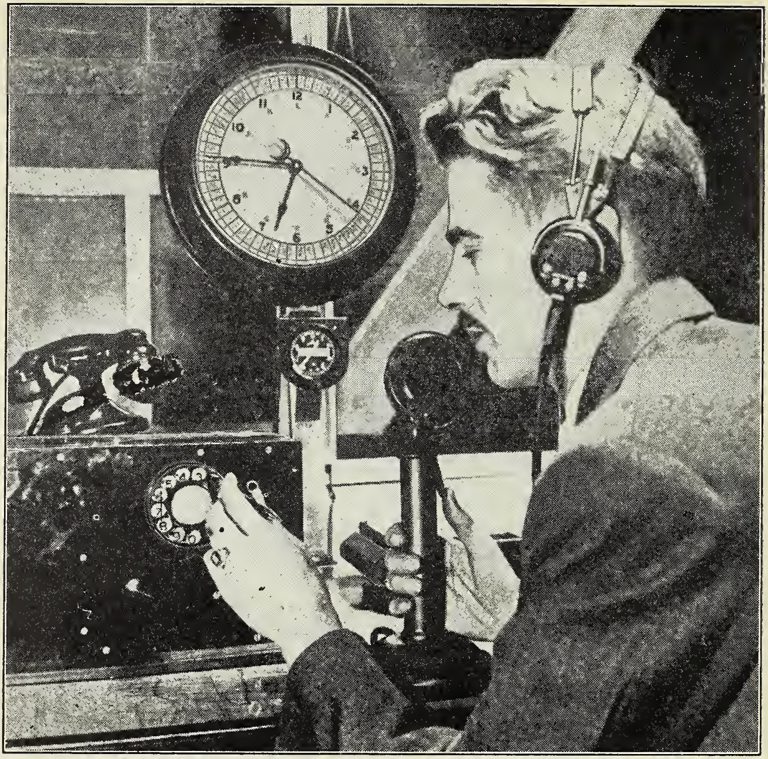
FIG. 299. A photograph showing the changes in an electric current when the word "telephone" is spoken into a transmitter.

voice cause the electric current in the receiving circuit to vary so that at the receiving end the sound waves are reproduced accurately by the disk. What flows through the circuit, sound or electricity? Study Figure 297 to see whether you can describe what happens at each of the points indicated.

PROBLEM: HOW IS ELECTRICITY USED TO COMMUNICATE BY RADIO?

The radio. It is not so difficult to believe that messages may be sent over wires, but to send them long distances through space without any visible means of communication seems unbelievable (Fig. 300). To sit comfortably in our own homes and hear a concert or lecture given in a place many miles away seems almost like magic.

A knowledge of electricity clears up many of the seeming mysteries concerning radio messages. You are familiar now with



Courtesy United Air Lines

FIG. 300. Do you want to talk to a plane? This radiophone "switchboard" permits the radio telephone operator to communicate with a plane in flight.

many of the facts regarding the flow of electricity through wires. You must also think of electric energy as being radiated in much the same way that heat and light are radiated. In comparison with the length of heat and light waves, radio waves are very long. They differ in length from a few meters to several thousand.

Since there is a wide range of wave lengths that may be used for sending radio messages, it is evident that to avoid the interference of waves from one broadcasting station with those of another, regulations are needed to assign a particular wave length to each station. These wave lengths are assigned to some extent according to international agreement. In the United States the Federal Radio Commission assigns a certain wave length to a certain commercial station. Inventions in sending and receiving apparatus are being perfected which will make it possible to use still shorter waves for radio transmission and reception.

What is a radio wave? To help you understand radio waves we shall first take up their length. The length of radio waves assigned to commercial broadcasting stations varies from 200 to 545 meters. Scientists tell us that radio waves travel at a speed of 300,000,000 meters per second (speed of light). If we divide 300,000,000 by 300 (the number of meters in a common radio wave length), we find that this wave vibrates 300,000,000 ÷ 300, or 1,000,000 times per second. As you know, the number of times a wave vibrates per second is called its frequency. Since the frequency of radio waves is so high, they are called *high frequency waves.*

To help you understand what has just been said, let us consider a more simple phenomenon. Suppose a bicycle wheel is two feet in circumference and it moves over the ground ten feet in a second. If we divide 10 by 2 we find that the wheel rotates 5 times in one second. We can say then that the frequency of the bicycle wheel is 5.

However, a radio wave does not rotate, it *oscillates*, that is, it moves back and forth, as you have just learned, about one million times per second. Because radio waves oscillate such a great number of times per second they are called high frequency oscillating waves. This is one of the facts you should remember about radio waves.

The radio vacuum tube. Before we can learn how radio waves are produced, we must study the radio vacuum tube. While experimenting with incandescent lamps, Thomas Edison tried the effect of placing a *plate* P in addition to the usual *filament* F (Fig. 301A) in an electric light bulb. He found that if the plate was connected through a galvanometer G to the positive terminal of the lighted lamp, a current was obtained through the galvanometer, but that there was no current if the connection was made to the negative terminal.

The electric current through the filament of an electric light bulb is a stream of electrons. When the filament is heated hot enough, these electrons fly off from the surface much the same as bubbles fly off from the surface of a glass of soda water. When the plate *P* is connected to the positive terminal, it has a positive charge and hence attracts these negative electrons and a current flows across the gap between the filament and the plate. No current flowed across the gap when the plate was attached to the negative terminal, because the negative charge would repel the electrons.

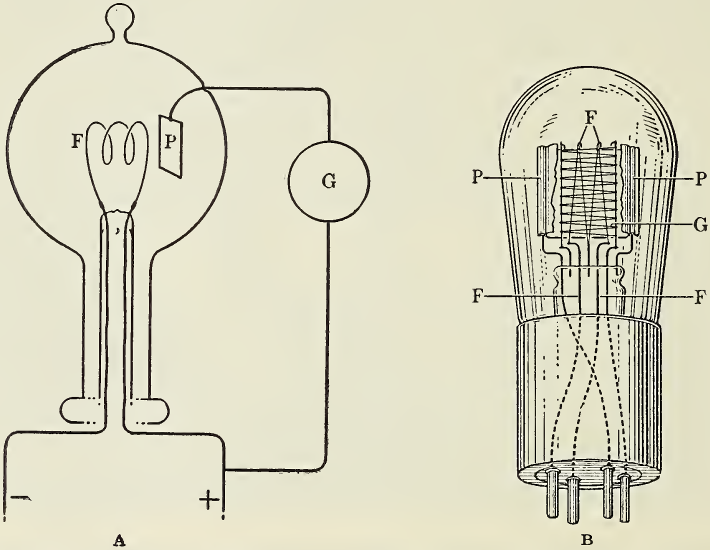


Fig. 301. Edison's original radio vacuum tube. Compare it with the more modern radio tube on the right.

The usual way of operating such a tube was to heat the filament with a current from a storage battery called the A battery. A second storage battery called the B battery was connected with its positive terminal attached to the plate and its negative terminal attached to the filament.

This original *vacuum tube* was greatly improved by DeForest by the insertion of a network of fine wire called the *grid* between the filament and the plate. The purpose of the grid is to change the flow of the electrons from the filament to the plate. If the grid has a negative charge, will it be easier or harder for the electrons to flow? Remember that like charges repel each other and unlike charges attract each other. If the negative charge on the grid is increased, it will be more difficult for it to flow from the filament to the plate. If the negative charge on the grid is decreased, what is the effect on the flow of electrons? So you see that varying the charge on the grid varies the flow of electrons from the filament to the plate.

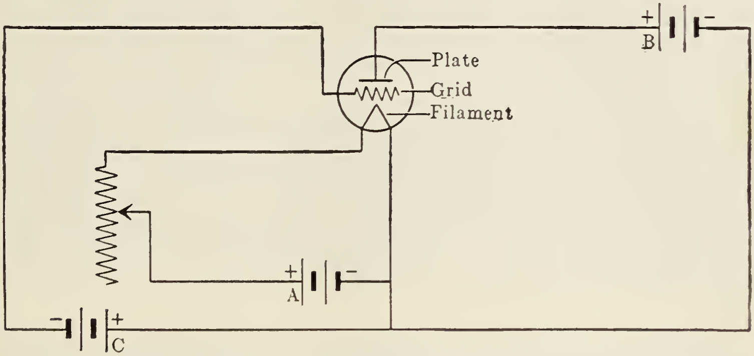


FIG. 302. What do the various symbols on this diagram represent? Trace the current used in the grid; filament; plate.

The common form of radio vacuum tube is shown in Figure 301B. In the center of the tube is the filament marked *F* surrounded by the grid, a network of fine wire. The plate *P* is in the form of a hollow cylinder surrounding the grid. At the bottom of the tube you will observe four contact points or terminals, two for the filament, one for the grid and one for the plate.

When this vacuum tube is operating (Fig. 302), the filament and the plate are attached to the A and B storage batteries as shown. In addition a third battery called the C battery is connected with its negative terminal attached to the grid, and its positive terminal to the negative terminal of the filament. Trace in this diagram the grid circuit, the plate circuit, and the filament circuit.

When a radio tube of this kind is used in producing radio waves, the grid circuit is attached to a special generator which creates a high frequency alternating current. This sets up a varying (pulsating) current in the plate circuit. This varying current pulsates thousands of times per second. By means of a transformer connected to an *antenna* the pulsating current in the plate circuit sets up (induces) an alternating current (oscillating thousands of times per second) in the antenna circuit. As this high frequency current flows through the antenna, a powerful electromagnetic field is set up around the antenna the same as a magnetic field is set up about any wire carrying an electric current.

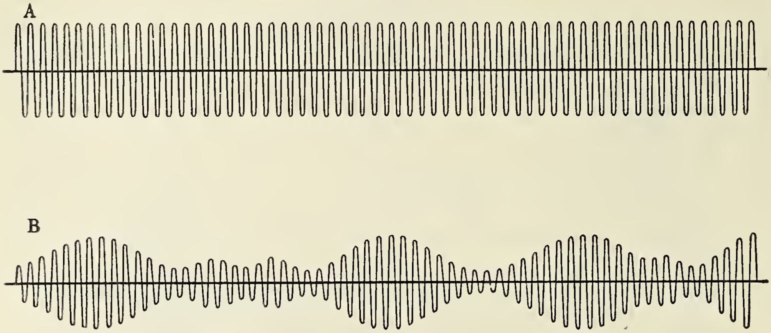
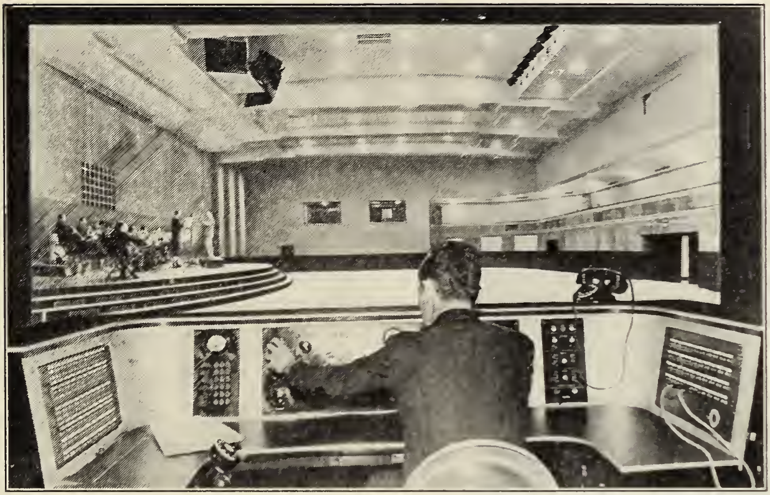


FIG. 303. *A*, radio carrier waves; *B*, carrier waves with a message impressed upon them.

The electromagnetic waves produced by the high frequency current in the antenna circuit travel out from the antenna as ever-expanding wave spheres much the same as sound waves travel in ever-expanding spheres from their source. These electromagnetic waves are known as *radio waves*.

Radio waves produced in this way are known as *carrier waves*. These are the waves that produce a sort of a hissing or humming sound in your radio receiving set when the broadcast program has been interrupted for a few moments. Carrier waves may be represented as shown in Figure 303A.

The sound waves produced by a speaker, singer, or musical instrument are changed to electrical impulses by an instrument called a *microphone*. These electrical impulses produced by a microphone modify the carrier waves as shown in Figure 303B. Sound waves cause the disk of the microphone to vibrate, causing



Courtesy National Broadcasting Co.

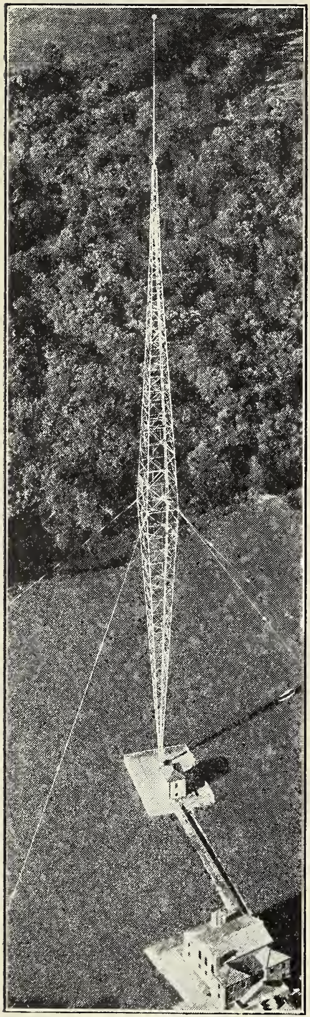
FIG. 304. View of one of the broadcasting rooms and control rooms in Radio City. The operator in the foreground by signalling the performers on the stage controls the broadcasting.

a varying current just as in the telephone transmitter. This varying current is mixed with the current producing the carrier waves and changes or modifies them as shown. The frequency of the waves is unchanged.

What is a broadcasting station? A broadcasting station is made up of two separate parts: (1) An electric power plant with equipment to send out carrier waves of the particular length assigned to that station; and (2) a studio where lecturers, actors, musicians and others broadcast.

What is a broadcasting studio? The room from which a radio message is broadcast is called a studio. Most broadcasting is done in specially constructed rooms in order to avoid troublesome echoes and reverberations. The walls and ceilings of the rooms are covered with or made of materials that tend to absorb sound waves which would interfere with broadcasting (Fig. 304).

Some radio stations consist of a large broadcasting room to accommodate orchestras and choruses; smaller rooms for broadcasting solos, lectures, and reports; a room for radio engineers who operate the control panels of the sending apparatus; a reception room for guests and artists; a suite of offices for executives in charge of the station; and a well-equipped storeroom. The walls of the broadcasting rooms, instead of being draped with monks cloth, velour, or other heavy material, as was often the case in older studios, are made of soundproof material.



Courtesy Columbia Broadcasting Co.

Fig. 305. The power plant and broadcasting antenna of a broadcasting station. This plant is located about ten miles from the studio.

No doubt when listening to a broadcast you have wondered how certain sounds are produced and also how some artists can represent a number of different characters, each having a different tone of voice. In most cases, the artist changes (varies) the sound of his voice in much the same way as you can change the sound of your voice. The distance and direction of a speaker's voice from a microphone also affects the sound of his voice.

The sound of a voice can also be changed by the use of a special microphone connected in a circuit in which there are filters that filter out certain tones such as the high tones or the low tones.

The loudness of a voice can be either increased or decreased by the operator who operates the control panel of the sending apparatus.

Often the broadcasting studio is located several miles from the electric power plant and antenna from which the waves are broadcast (Fig. 305). The microphone in the studio is connected with the broadcasting station by a telephone circuit. If a lecture is to be broadcast from several stations in a national hook-up, the microphone is connected with each of them by a separate telephone circuit.

How is a radio message received? You have just learned that high frequency radio waves are sent out from broadcasting antenna as ever-expanding spheres. You know too that when lines of force cut through a conductor an electric current is induced in the conductor. Similarly when these radio waves cut through the antenna of a receiving set they set up a very feeble alternating current in the antenna much the same as a current is set up in a wire cut by the lines of force of a magnetic field.

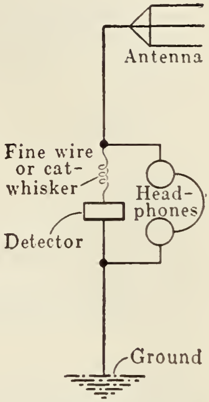


Fig. 306. A crystal receiving set.

The crystal receiving set. We will study first the simplest receiving apparatus, which is a *crystal set.* We can use such a set for short distances only, as waves from more distant stations tend to die out and thus become too faint to affect it. Referring to Figure 306 you will notice part of the equipment required is an antenna, which may be a single wire from house to garage or barn, a loop of wire inside the house, or a specially prepared socket to be placed in the wiring system of the house. Other equipment needed is: a detector, a pair of telephone receivers, and a ground connection. The *detector* consists of a cup-like metal box containing a crystal, usually lead sulfide (galena), and a loose connection referred to as a "cat whisker." As the antenna is cut by the radio waves a very feeble alternating current is set up and is conducted to the detector. Crystals of galena permit electric currents to pass through them more easily in one direction than in the other, thus changing an alternating current to a direct current. The radio waves indicated in B, Figure 303, are changed, when the current becomes direct, to waves as represented in A, Figure 307. By this means the sound waves that are impressed on the radio waves can be heard through the headphones. The disks in the headphones reproduce accurately the vibrations produced by the speaker's voice. These vibrations of the disks produce waves in the air (Fig. 307B) which we hear as the speaker's voice.

The battery receiving set. In this kind of receiving set the antenna is connected to the grid of the vacuum tube. The feeble alternating current from the antenna sets up varying charges on the grid which cause corresponding changes in the plate circuit.

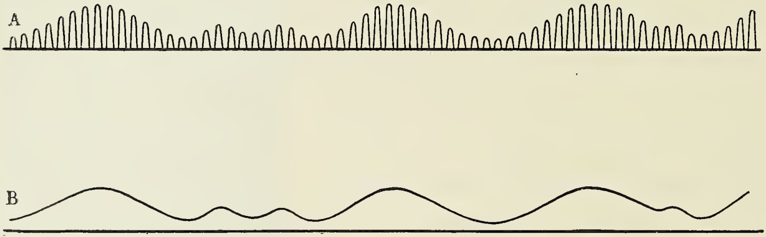


Fig. 307. Compare the radio waves shown in *A* with those in *B* of Fig. 303. In *A*, the radio waves have been rectified by either a crystal or a vacuum tube. *B* represents only waves that the human ear can hear.

In this way the feeble current from the antenna is made much stronger (amplified) in the plate circuit. In the same way the current in the plate circuit can be amplified still more by passing it through one, two, or three successive amplifying tubes.

This alternating current is not suitable for the operation of a loud-speaker and must be changed by means of a detector tube. This modified current is increased by sending it through additional amplifying tubes and it then passes to the loud-speaker where it operates a disk much the same as the disk in headphones. The vibrations set up in the air by the disk are the same as the vibrations produced by the speaker's voice which operated the disk in the microphone. When these vibrations in the air strike upon the ears of the listener he hears the speaker's voice.

What is meant by tuning a radio receiving set? As you learned on page 487, in order to avoid confusion in radio reception, our national government determines the wave length on which each station is permitted to broadcast. To receive a program from a particular station you must tune your receiving set to the particular wave length used by the station sending the program.

Figure 308 illustrates the circuit of a simple receiving set. You must remember that radio waves from several broadcasting stations are cutting the antenna and consequently several alternating currents are set up in the antenna. Tuning the set consists of arranging a path which will allow a particular alternating current to flow and exclude all others. This is done by placing a variable condenser in the circuit as shown. When the dial attached to the variable condenser is turned, a certain position will allow a particular alternating current to flow more freely in the circuit than any of the others. This particular alternating current produces a varying charge on the grid and consequently produces a varying current in the plate circuit which is reproduced by the headphones as the program sent out by the broadcasting station.

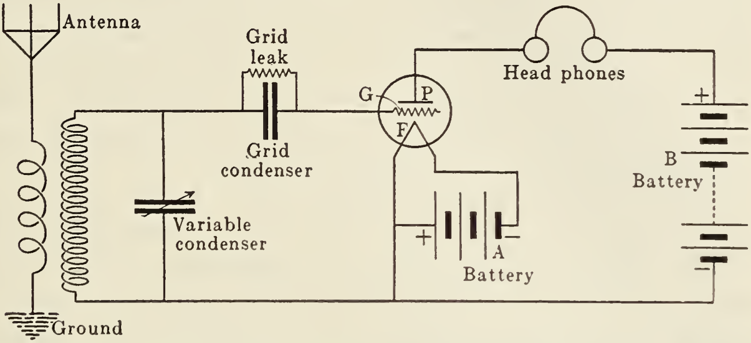


FIG. 308. A vacuum tube receiving set that requires batteries. Why?

By turning the dial attached to the variable condenser, another position will allow an alternating current produced by radio waves from some other broadcasting station to flow in the circuit and in the same way the program from that station will be reproduced by the headphones.

Alternating current receivers. Most radio sets now use alternating current from the ordinary electric light socket instead of direct current from batteries. In sets of this kind the filament of each vacuum tube is heated either directly or indirectly by alternating current, thus eliminating the A battery. By means of rectifying tubes, the alternating current from the lamp socket can be changed into a direct current and supplied at the proper voltages and so eliminate the B and C batteries. This type of receiving set is called an "all electric" set.

Wireless telegraphy. In wireless telegraphy the message is sent in the form of dots and dashes in the telegraphic code. These dots and dashes are transmitted as short and long buzzing sounds and are controlled by a telegraph key. The message comes to the receiving set in the form of short and long buzzes. These are translated into words by the person receiving them the same as dots and dashes from a telegraph sounder.

Where are public address systems used? Public address systems are used in many ways. In a large auditorium seating several thousand people a speaker or singer cannot be heard distinctly by the people farthest away. This difficulty is overcome by the use of a public address system. Undoubtedly you have heard a system of this kind used at athletic contests, such as baseball or football. At football games an outline of the game is given by such a system as the game is played. At some baseball games the line-up and substitutions are announced by a public address system. Perhaps you have such a system in your school whereby announcements are made to the pupils in the rooms.

How does a public address system operate? You will remember from your study of radio that a carrier wave is necessary to carry the message from a broadcasting station to the receiving sets. In a public address system a carrier wave is not necessary because the message is confined within a building or a small area, such as an auditorium, a baseball field or gridiron. The only requirement is to amplify the vibrations produced by the speaker's voice by means of one or several loud-speakers. In order to accomplish this the varying current produced by the diaphragm in the microphone is used to set up varying charges on the grid of a radio tube and a similar varying current is set up in the plate circuit. This varying current in the plate circuit is amplified and conducted to one or more loud-speakers, which reproduce the speaker's voice.

PROBLEM: HOW IS ELECTRICITY USED IN TRANSPORTATION?

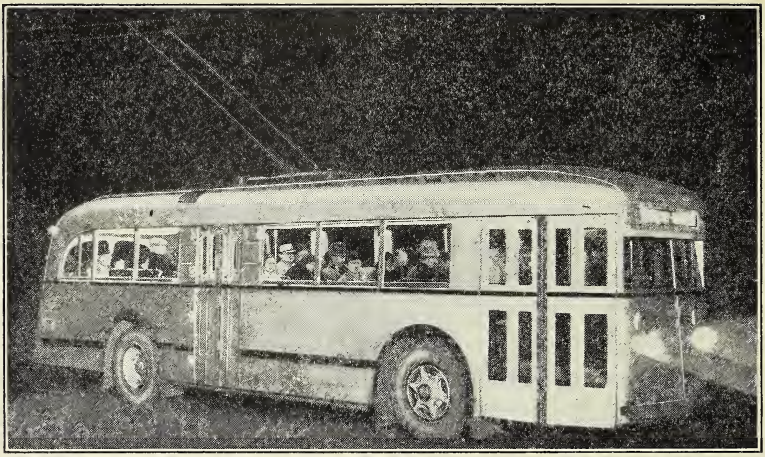
Streetcars and buses. The electric streetcar was probably the first vehicle to use electricity for transportation. Because of the rapid increase in the number of automobiles and motor buses in the United States, the number of streetcars used has gradually decreased. However it seems quite likely that they will be used for many more years.

To operate a streetcar a direct current with a voltage of from 500 to 600 volts is used. It flows from a generator at a power station through a wire which is above the track on which the car runs. From the wire the current flows through a trolley wire to the motors. On leaving the motors it flows through the metal wheels of the car to the tracks. The car tracks serve as the other wire which is needed to complete the circuit.

Trolley cars are propelled by two or four motors, each capable of developing 40 horsepower. A motor also pumps air into a tank which is used to operate the air brakes (page 33). Air is pumped into the tank until a certain pressure is reached; then the current is automatically shut off. When air is used from the tank, the pressure decreases. When a certain pressure is reached, the current is automatically turned on. Then the motor starts operating again.

Streetcars are being displaced by passenger buses of different kinds. In some cities streetcar tracks have been removed but the trolley wires have been retained. Electric buses (trolley buses) operating much the same as streetcars are now used. Two trolley poles extend above the top of the bus and run on the trolley wires to conduct electricity to the motor. Buses of this kind may follow the middle of the street beneath the trolley wires or move over to the curb to take on and discharge passengers. These buses are easy to operate and because they are equipped with rubber tires are much quieter than streetcars.

Regular passenger buses which operate much the same as an automobile are also used in cities. The motivepower for a bus of this kind is furnished by the usual automobile engine. The buses are free to move about the street the same as other vehicles. With



Courtesy J. G. Brill Co.

FIG. 309. Trolley buses are easy to operate, make little noise and produce no exhaust gases.

transportation of this kind, suburbs to large cities are enabled to have transportation where it would be too costly to build streetcar lines. Bus transportation between cities has become firmly established. Regular schedules are maintained between cities. Modern buses furnish transportation from coast to coast and from Canada to the Gulf of Mexico. How is electricity used in operating a bus?

Electricity and the gas motor. Although we say sometimes that this is the age of the automobile or the gas motor, we must not forget that the automobile, the tractor, the motor boat, the airplane, and indeed every machine operated by gasoline or kerosene fuel, also depends upon electricity for its operation. Can you mention one exception? The source of the current for a gasoline motor is a storage battery. This current, like that from all batteries, is a direct current.

When the ignition key of certain automobiles is turned on, an electric circuit is closed, and the current produced starts a small electric motor which in turn operates the starter. The starter in turn revolves the crankshaft, thus starting the movement of the pistons in the cylinders. At the proper moment an electric spark from a spark plug ignites the gas mixture which has been forced into the cylinder and thus the gasoline engine begins to operate. The spark plugs, of course, use electricity as the motor operates.

The horn on an automobile is operated usually either by a small electric motor or by a vibrator which causes a metal disk to vibrate rapidly. Its vibrations transmit sound waves through the automobile horn.

To keep the storage battery charged properly, a small generator run by the engine produces a direct current which is conducted to the battery. Whether the battery is being charged or is discharging is shown by the needle of an ammeter on the instrument board in front of the driver. What position of the needle indicates the battery is being charged? Is discharging?

The electric automobile. An automobile driven by an electric current is operated very much like a street car with the exception that it carries its supply of electricity with it in storage batteries. An electric passenger automobile is driven by a motor of about three and a half horse power. Electric trucks and delivery cars have motors several times as powerful. The energy of a fully charged storage battery of three cells has been known to drive a car from fifty to one hundred miles. This distance depends somewhat upon the speed at which the car is run. At high speed the resistance of the wind uses up part of the energy.

Electric lights on a steam train. The lights first used on steam trains were kerosene lamps which had to be fastened securely to keep them from breaking or from spilling oil. Later, compressed gas was used from storage tanks.

Electric lamps are in general use on steam and electric trains today. Probably you have observed a small belt running over pulleys under a passenger car. If you look more closely you will observe that this belt is being driven by a pulley attached to the axle of the car and that it is operating the armature of a small electric generator. The current from the generator is sent to storage batteries under the car. These batteries furnish electric current for lighting the lamps and driving the fans on the trains.

The electric locomotive. During recent years the electric locomotive has been gradually replacing the steam locomotive as the motive power for trains. Some railroads are operating their trains entirely by electric locomotives, partly because a steam locomotive is very inefficient. It is calculated that one pound of coal burned in a steam turbine generating electricity, will produce four times as much power as a pound of coal burned in the average steam locomotive. In the mountainous parts of our country the electric locomotive effects a saving while it is running down long grades, for its motors can be made to generate electricity which can be fed back into the power line. At the same time the resistance offered by the motors serves as a brake. The recent development of huge hydroelectric plants makes electric power cheaper than power from coal in many parts of the country.

The use of electric trains is highly desirable in large cities and in thickly populated districts because they can be operated without smoke and are very efficient in handling heavy traffic on fast schedules due to the rapidity with which they can start and stop. Where trains must run through tunnels, electric engines are a great advantage as they do not produce smoke.

An electric locomotive operates somewhat like an electric street car. However its motors are more powerful because they have to move a much heavier load. Some large electric freight locomotives have motors capable of developing about 3000 horse power. These operate by means of a direct current flowing under an electric pressure of 2500 to 3000 volts.

Electricity on ships. A ship propelled by steam is usually equipped with its own electric power plants for generating current to be used for lights, cooking, sending signals and messages and for operating elevators, and the like.

The first extensive use of electricity for propelling ships was in submarines. While the submarine is on the surface it charges large storage batteries by means of gasoline or oil engines. Under the surface it is propelled by electric motors which use current from storage batteries.

Modern ships, especially battleships, often use electricity for power. We have learned that the steam turbine is much more efficient than the steam engine, and besides, it runs smoothly without the vibrations that are so undesirable on a ship. But steam turbines run most economically at high speeds. Consequently, some means must be employed to transmit the power to the propeller in such a way as to permit the turbine to run at high speed and still allow for the slower speed of the propeller. One of the methods of accomplishing this is to connect the turbines directly to high speed alternating current generators. The power thus generated is employed to operate large slow-speed electric motors connected directly with the propellers.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

amplifier
antenna
broadcast
carbon particles
carrier wave
circuit breaker
code
communication
condenser
crystal set
demagnetize
detector
diaphragm
filament
frequency
galena
grid
induction coil
microphone
oscillation
plate
pulsation
radio
receiver
relay
sounder
spark plug
telegraph
telephone
transmitter
trolley
tuning
vacuum tube
varying current
wireless
wave length

Write the number of each item on your paper and after it the word that completes the statement.

1. When you push the button of an electric door bell the circuit is ________.

2. The sounder bar of a telegraph instrument is operated by ________.

3. A varying current is set up in a telephone circuit by ________ in the transmitter.

4. In a telephone circuit the varying current is changed into a ________ by means of a transformer.

5. The ________ of a radio tube is heated to incandescence.

6. In a radio tube ________ flow from the filament to the plate.

7. In a radio tube the charge on the grid controls the flow of current in the ________ circuit.

8. When radio waves cut the antenna of a radio set a feeble ________ is set up in the antenna circuit.

9. The means by which an electric street car is moved is a ________.

Which item in each of the following lists does not belong with the others?

10. electrolysis; electric bell; electromagnet; alternating current; dry cell.

11. radio wave; electromagnetic wave; high frequency; oscillating; loudspeaker.

12. telegraph; sounder; key; transmitter; relay.

Which of these statements are true? If any are false, re-state them in correct form.

13. When an electric door bell is ringing a continuous current flows through the circuit.

14. When a person talks into a telephone transmitter an alternating current is set up in the transmitter circuit.

15. The plate in a radio tube gives off electrons.

16. An automobile in good condition generates the electricity needed for its operation.

THOUGHT EXERCISES FOR UNIT XII

Principles of Science

State the principles in this unit in sentence form. One of them is: Like magnetic poles repel each other.

Questions or Problems

1. Why do electricians when working around high voltage electric currents wear rubber gloves?

2. What did Franklin prove by his experiment with the kite?

3. If you rub your hand over a cat's back in a dark room, sparks may be seen. How are these sparks similar to lightning?

4. Should lightning rods touch the materials of a building or be insulated from them? Why?

5. Name two uses of the can in a dry cell.

6. What happens to a fuse when it "blows" out?

7. If a fuse "blows" out why is it dangerous to place a cent into the fuse socket? Would the same danger be present if an ordinary copper wire were placed across the contact points of an open fuse?

8. Give two reasons why copper is a good material for electric wiring.

9. The sailors with Columbus became alarmed when they noticed the magnetic needle no longer pointed to what they thought was north. Explain the cause for this change of direction of the compass needle.

10. What causes a motor to rotate? A generator?

11. If you saw a person in contact with a "live" wire how would you remove him?

12. What three nationalities are represented in naming the units of electricity?

13. In an electroplating tank why is metal deposited on the negative pole?

14. Why is direct current necessary to do electroplating?

15. If a current of electricity carries an amperage of 5 and a voltage of 115, what is the resistance?

16. How many amperes does a 100-watt lamp use if it is connected in a 115-volt circuit?

17. Would modern communication be impossible without the use of the electromagnet? Give reasons for your answer.

18. What may be done to make an electromagnet more powerful?

19. When speaking over the telephone how far do the sound waves of the voice travel?

20. Where are the sound waves changed to a varying electric current in a telephone transmitter?

21. Explain how an alternating current is changed to sound waves in the telephone receiver.

22. In what ways is the operation of a telephone similar to that of the radio?

23. Is the term "relay" as used in connection with telegraphy a good one? Discuss your answer.

24. If an inside aerial is used, must the radio waves pass through the walls of the house? What does this tell you about radio waves?

25. How was the vacuum tube a great factor in the rapid development of wireless communication?

26. What parts of an automobile would be removed if it were deprived of the use of electricity?

27. What furnishes electricity for light on railroad coaches when the train is standing still?

28. What present means of traveling and transportation make use of electricity?

29. How does an electric train use gravity to generate electricity?

Projects and Reports

1. Visit the electric plant which furnishes current for your home, and report in detail your observations to the class.

2. Study and report to the class the possibility of using wind power for charging storage batteries in rural districts and small towns that do not have access to electric power lines.

3. Make a study of the life of Alexander Graham Bell, Samuel F. B. Morse, Joseph Henry, Thomas Edison, or Michael Faraday. Report upon their discoveries or inventions to the class.

4. From an old storage battery select a positive and a negative plate which appear to be in fairly good condition. Immerse these in a sulfuric acid solution having a density of 1.13. Connect these in a circuit with a door bell. Demonstrate this type of battery before the class.

5. Have members of the class select one of the following subjects for a construction project. Construct and operate one of the following: Electromagnet, motor, galvanometer, voltaic cell, arc lamp, toaster, heater, electric furnace, electroplating apparatus, telegraph set, or radio set.

Read as widely as possible on your particular subject. When making your report; (1) tell something about the scientist who discovered the principle underlying your project; (2) explain the construction of the apparatus: (3) demonstrate its operation; (4) discuss the use of your project in our everyday life; (5) answer the questions asked by other members of the class.

Your teacher may ask you to make your report at the time your class is studying the subject you have chosen.

6. Those members of the class who do not have the opportunity to construct apparatus may give a demonstration of an electric device used in everyday life such as: the electric iron, door bell, motor, toaster, heater, telegraph set, ammeter, voltage meter, etc.

Prepare to give a report to the class as indicated in the preceding projects.

REFERENCES FOR READING AND STUDY

1. Collins, A. F., *The New World of Science* (Photoelectric cells). J. B. Lippincott Company.
2. Collins, A. F., *Fun with Electricity.* D. Appleton-Century Company.
3. Darrow, Floyd L., *Thinkers and Doers*, Chapters II and XVIII. Silver Burdett Company.
4. Floherty, J. J., *On the Air.* Doubleday, Doran & Company.
5. Hathaway, Kenneth A., *Modern Radio Essentials.* American Technical Society, Chicago.
6. Lincoln, E. S., and P. C. Smith, *The Electric Home.* The Electric Home Publishing Company, New York.
7. Lunt, Jos. R., *Everyday Electricity.* The Macmillan Company.
8. Meister, Morris, *Magnetism and Electricity.* Charles Scribner's Sons.
9. Timbie, Wm. H., *Elements of Electricity.* John Wiley and Sons, New York.
10. Willoughby, Geo. A., *General Electrical Work.* Manual Arts Press, Peoria, Illinois.
11. Wright, Forrest B., *Electricity in the Home and on the Farm.* John Wiley and Sons.
12. Yates, Raymond F., *How to Make Electric Toys.* D. Appleton-Century Company.
13. Yates, Raymond F., *These Amazing Electrons.* The Macmillan Company.

UNIT XIII

HOW DO PLANTS MAKE FOOD AND STORE UP ENERGY?

Exploring the Plant World

Almost every boy and girl has a bountiful supply of energy. Older people marvel at the tireless activity of youth. Have you ever wondered where your energy came from? You have learned that the sun is the source of the useful energy on the earth. But have you ever wondered how energy from the sun can be used by you to walk, run, play games, and do your work? Of course, you will say that your energy comes from the food you eat. But how does it happen that energy from the sun is stored in food? The answer is that plants are able to use energy from the sun to make food. You can think of every green plant as a factory which is using energy from the sun to manufacture food used either by itself or by man and the lower animals.

Civilized man has learned which of these marvelous factories is best suited to produce his food and he cultivates them with care and protects them from their enemies. He has learned how these plants reproduce their kind and because of this knowledge he is able to grow them year after year and thus provide himself with a permanent supply of food. Because domesticated animals must secure their food from plants, man also cultivates and protects the plants which furnish food for them.

Not only do plants furnish man with food but also a variety of materials that he uses in making clothing and supplying many of his other needs. The energy stored up by green plants ages ago aids man in doing his daily work. For example: This stored up energy runs the machines in his factories, drives his trains, propels his ships, and lights and heats his home.

No doubt, you are wondering how it is that plants are able to capture and store up such a vast supply of energy. This unit will tell you how the wonderful factories in green plants make food and store up energy.

CHAPTER XXVI

HOW DO PLANTS GROW AND STORE UP FOOD?

Do you know:

That plants are made up of very small building blocks? That plants are composed of some of the same elements that make up our bodies? How roots take in food for a plant? Why leaves are sometimes referred to as manufacturing plants? That all food for plants is in either the liquid or in the gaseous state? That stems contain a double transportation system to convey food for the plant?

That flowers are necessary for the reproduction of certain plants? Why insects are attracted to flowers? Why the stamens and pistils of flowers are necessary for pollination?

That a bean or a peanut contains inside a "baby" plant tightly folded up? That plants absorb food by the same process that animals absorb food? How plants make and store up food for man and the lower animals?

PROBLEM: WHAT IS THE SIMPLEST BUILDING BLOCK IN LIVING MATERIAL?

You know that everything on the earth, whether rocks or trees, earth or animals, air or birds, must be made up of combinations of the ninety-two elements. Scientists have found that all living matter (and of course we must include substances like wood, wool and rubber that come from plants or animals) consists mainly of just four of these elements: carbon, hydrogen, oxygen, and nitrogen. Why should some compounds of these four elements be living matter and other compounds of the same elements non-living? How can we tell living matter from non-living matter?

You may be interested to know what elements make up the human body. Sixty-five per cent of the weight of a human body is oxygen; 18 per cent carbon; 10 per cent hydrogen; 3 per cent nitrogen; and the remaining 4 per cent is calcium, phosphorus, and traces of other elements. Of course, none of these occur as elements in the body, but as compounds of two or more of them.

How does living matter differ from non-living matter? First of all, all living matter can *move.* You have observed the motion of animals, athletes running on a track, birds flying in the air, and fish swimming in the water. Probably you have observed also the motion of plants: leaves turning to the light, a flower shutting its petals at night, a sunflower keeping its face toward the sun. All living matter is *sensitive,* that is, it is affected by heat, light and touch. All living matter *breathes.* How do animals breathe? Fishes? If you do not already know how plants breathe, you will learn in this chapter. All living matter *takes in food.* Where do plants get their food?

All living matter is able to *grow.* It is true that non-living matter sometimes becomes larger and seems to grow, but it does so only by taking on more matter on the outside. For example, an icicle becomes longer and thicker as more water freezes on it. Living matter grows in a different way. Plants and animals take food into their bodies and transform it into living matter.

In addition to the fact that living matter (1) moves, (2) is sensitive, (3) breathes, (4) takes in food, and (5) grows, it also (6) gives off waste material and (7) reproduces itself. This chapter will teach you how plants perform the functions of living things.

What is the structure of living matter? The following experiment will help you to discover the structure of living matter.

Experiment 140. To study the structure of an onion skin. (The teacher should prepare the slides for use by the class.) Examine under a microscope a slide prepared from the epidermis (outer layer or skin) of an onion (Fig. 310), which has been stained with iodine. What do you see? Does the structure of the onion skin remind you of the structure of anything else that you have seen?

What is a cell? You have just observed that the onion skin consists of tiny rooms, called *cells.* Careful observation of a single cell shows that a *cell wall* encloses a bit of living matter called *protoplasm.* Embedded in the protoplasm is a slightly darker mass of protoplasm called the *nucleus.* A cell, then, has three distinct parts: (1) cell wall; (2) protoplasm; and (3) a nucleus.

How many kinds of cells are there? All living matter, whether found in microscopic plants or giant trees, in the smallest of animals or in the body of an elephant, consists of cells. There seem to be as many kinds of cells as there are kinds of plants and animals. The cells of a horse are not the same as the cells of a cow. That is why a horse looks and behaves differently than a cow. But the difference in cells of animals or plants goes still further. The cells in the muscles of a horse are not the same as the cells in his nerves, skin or other parts of his body. The cells in a root are not the same as the cells in a leaf. You can see, then, that there must be many different kinds of cells even in the same plant or animal.

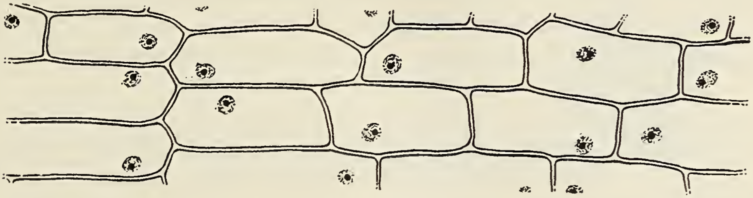


Fig. 310. Cells of a thin layer of onion tissue greatly magnified.

What are tissues? The most common plants and animals consist of a highly organized system of cells. In a plant certain kinds of cells form leaves, other kinds form roots, and still others stems. In an animal, certain kinds of cells form muscles of various kinds, others form fat, others nerves, still others bones, and so on. A mass of cells of the same kind, existing as a unit, is called a *tissue*. A group of different kinds of tissues that work together to perform a particular function is called an *organ*. The leaves, stem, and roots of a plant and the heart, lungs, liver, and brain of an animal are organs. Why do you think that a highly developed plant or animal can be called an organism?

How does living matter grow? Most plants and animals are made up of millions of cells. There are also plants and animals made up of one cell. *Bacteria* are tiny one-celled plants; the amoeba and the paramecium are one-celled animals. Many plants and animals, organisms which in adult life are composed of countless cells, have developed from a single cell. A tree or a horse begins life as a single cell. Under favorable conditions of heat, moisture, and food this single cell will divide to form two cells. These, in turn, divide to form four cells, and so on until a complete organism is formed. Every organism continues to maintain itself by cell repair and cell division as long as it lives.

What is cell division? Figure 311 shows the steps in the division of a cell. *A* represents a fully developed cell; observe the nucleus. In *B* what has happened to the nucleus? *C* and *D* show the nucleus separating into two parts. In *E* the remainder of the cell has begun to divide. Finally, *F* shows two cells about to separate and form two individual cells like the original cell *A* except that they are smaller. Each of these cells will grow to adult size and then divide. Cell division, whether in a one-celled plant or animal, or in an organism composed of millions of cells, takes place in very much the same way.

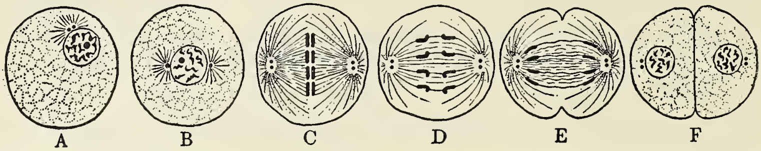


FIG. 311. By cell division such as is shown here all living tissue grows.

Why will you stop growing in height? Since the living cells which make up an organ take in food and transform it into living matter, each cell grows in size. This growth of a cell and the increase in the total number of cells because of cell division increases the size of the organs of a plant or animal, and thus the whole plant or animal *grows*.

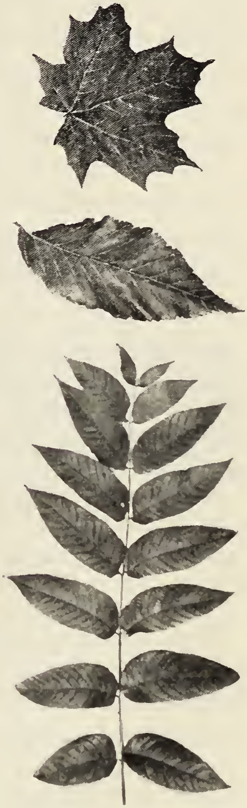
But cells are constantly changing and dying even though the organism goes on living. Some of the cells in your body are used up as fuel to keep it warm and to provide the energy which you need. During childhood and youth the growing processes occur more rapidly than the breaking down processes and so the child grows in height and weight until he becomes an adult. Even then he may increase in weight. When living material is breaking down as rapidly as new living material is formed, a person remains the same size.

Explain what happens when a person gains or loses in weight.

PROBLEM: HOW DO LEAVES MANUFACTURE FOOD?

No doubt you have observed that the leaves of different plants are not alike? The shape and color of the leaves of a plant furnish one means of recognizing the plant. Boys and girls who live in the country can tell from the leaves of a tree whether it is an oak, a birch, a pine, a sycamore, a maple, or an elm. Probably girls and boys in the city know the leaves of the maple, the elm, and the poplar. What trees can you recognize from their leaves? Name other plants whose leaves you know.

Experiment 141. To observe the parts and structure of leaves. Bring to class leaves from at least three different kinds of plants. Hold each leaf to the sun. Can you see lines, or *veins?* Make a sketch of each leaf and label the sketch with the name of the plant on which the leaf grew.



Courtesy L. W. Brownell and U. S. Forest Service

FIG. 312. Different kinds of venation in leaves.

The main part of a leaf is called the *blade;* the stem which attaches a leaf to a branch is the *petiole.* The leaves of most kinds of plants have veins which help to keep the leaves firm and to determine their shape. Veins also serve as tubes through which food is transferred from roots to leaves and back again.

There are several kinds of arrangements of the veins in a leaf (Fig. 312). Study the arrangement of the veins in the leaf at the top, the *palmate-veined* leaf of the maple. Do its principal veins branch out from the petiole like the ribs of a palm leaf fan? The leaf of the birch, shown in the middle leaf, has a main vein from which tiny veins extend on either side to the edge of the leaf. This arrangement reminds us of a feather, hence such a leaf is said to be *pinnately veined* (pinnate means feather-like). Walnut leaves are shown at the bottom. Notice that these leaves are made up of more than one part; such leaves are said to be *compound* leaves. How is each part of the walnut leaf veined?

How are leaves arranged on plants? The place on the stem of a plant from which a leaf grows is called a *node.*

When just one leaf grows from each node on a branch the arrangement is known as *spiral* or *alternate.* Is most of the space on either side of the branch occupied? Is there much overlapping of the leaves? Explain how this alternate arrangement of leaves on a branch permits each leaf to receive sunlight on all of its surface. Examine the length of the petioles of the leaves which grow two from each node. How does the difference in the lengths of the petioles help the leaves to receive sunlight on their surfaces?

Experiment 142. To study the two main arrangements of leaves on a stem. Find three plants that have but one leaf growing from a node. Examples of such plants are the rubber plant, the chestnut, oak, linden, and tulip tree. Make a sketch of a branch from one of these plants showing the arrangement of leaves upon it.

In the same way, find plants that have two leaves growing from each node. The leaves of the maple, ash, and horse chestnut tree are arranged in this way. Make a sketch of a branch showing this type of arrangement.

Where do buds grow on plants? During your observations no doubt you noticed buds beginning to form in the angle between the petiole of the leaf and the stem. Some of these are leaf buds; some are flower buds; and others may develop into branches. In cold climates these buds are often protected through the winter by tough scales covered with resin. In warmer climates buds in general are not so protected.

Experiment 143. To observe the openings in the under-side of a leaf. (The teacher should prepare the slides for use by the class.) Observe under a microscope a slide prepared from a very thin piece of epidermis from the under-side of a geranium or begonia leaf. What do you see?

How do gases pass into and out of a green leaf? The skin, *epidermis,* of the under-side of a leaf has tiny openings called *stomata.* A single opening is called a *stoma.* The stomata of most kinds of plants are so small that they cannot be seen except with a microscope. Each stoma is surrounded by cells called *guard cells* which expand and contract, thus opening and closing the stoma. Through the stomata pass in and out the gases used or given off as the leaf performs its functions. If the stomata become clogged, the leaf will die. Dust from a road or smoke from a factory may kill a plant by clogging its stomata. Sometimes the leaves of an ivy or other house plant are washed to remove dust. What effect would this have upon the health of the plant? Would you expect shade trees in a city to be as healthy as those in a residential suburb? Give a reason for your answer.

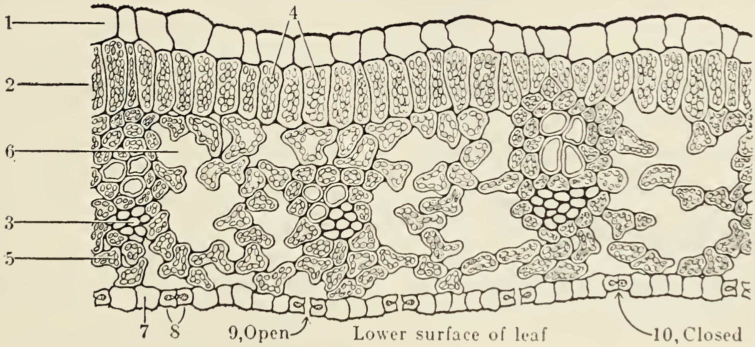


Fig. 313. A thin slice of lily leaf magnified: 1, upper epidermis; 2, palisade layer; 3, vein; 4, chlorophyll bodies; 5, spongy layer; 6, air spaces; 7, lower epidermis; 8, guard cells; 9 and 10, stomata.

What kinds of cells are there in a leaf? Figure 313 shows the cross section of a leaf. Find the stomata on the lower surface. Does the upper surface have any stomata? Suggest a reason why the stomata are on the lower surface. Just beneath the upper epidermis is a layer of cells called the *palisade* cells. What is the shape of these cells? Beneath the layer of palisade cells another layer of cells irregular in shape forms a spongy tissue. Notice the air spaces in this layer. Are the stomata connected with these air spaces? The cross sections of the veins that run through the leaf are shown as openings in this diagram. The small green bodies which you saw under the microscope when you examined the begonia or geranium leaf are *chlorophyll bodies* (chloroplasts). The numerous chlorophyll bodies in a leaf make the leaf appear green. From your study of light explain what part of sunlight, light waves, these chlorophyll bodies must absorb in order to appear green? What light wave is reflected to the eye?

The leaf as a factory. One of the main differences between a green plant and an animal is that a green plant manufactures food and stores up energy; whereas an animal eats and digests food made by green plants, thus releasing the energy stored-up by the plants, and uses this energy for heat and movement. The leaf of a green plant is a factory in which food is manufactured and energy stored. The power which runs the factory is sunlight. Figure 313 shows the machinery in the factory. Let us see what takes place in this factory.

Comparison of a Leaf to a Factory

Factory	*Leaf*
1. Building and entrances	1. Blade, petiole, veins, and stomata
2. Machinery	2. Chlorophyll bodies
3. Raw materials	3. Carbon, oxygen, hydrogen (carbon dioxide and water)
4. Power (steam, electricity)	4. Sunlight
5. Finished product	5. Starch and sugar
6. By-products	6. Oxygen and water vapor

The raw materials enter the leaf factory through two entrances. Water, with mineral matter dissolved in it, enters the roots of the plant, travels up the main stem and the branches, to the petiole of the leaf. From the petiole veins distribute the water solution throughout the leaf factory. Air enters the leaf factory through the stomata. The leaf factory uses only the carbon dioxide in air.

The chemical process, called *photosynthesis*, set up by sunlight in the leaf factory changes the raw materials into starch and sugar. Photosynthesis takes place in all the green parts of a plant—in new stems and twigs as well as in the leaves. The machines in the leaf factories are the chlorophyll bodies, which can work only when light energy from the sun acts upon them.

In most factories, not only a main product is made but also certain by-products. This is equally true of the leaf factory. Usually there is a surplus of water given off through the stomata as water vapor. This water vapor was originally taken in as water by the roots in order to get the minerals dissolved in it. As much as one hundred gallons of water may be given off as vapor from the leaves of an average-sized tree on a summer day. Does water vapor given off from plants have a cooling effect on the surrounding atmosphere? Explain. A more important by-product of the leaf factory is oxygen. The materials which are used by the plant to make starch and sugar by photosynthesis contain more oxygen than is needed in the finished product. This oxygen is given off through stomata. What use do animals make of oxygen?

The leaf factory works only in sunlight, as the sun furnishes the energy to run the chlorophyll machines. Cloudy weather slows up production in the leaf factory. A plant such as a potato will grow for a short time in a dark place, like a cellar, but only because it uses the food which is stored up in its root or stem. As soon as this food is used up the plant dies. Since the leaf factories furnish the food on which we all live, you can see that all of our food depends on light from the sun.

Problem: How Do Roots Take Raw Materials From the Soil for Use in the Leaf Factories?

Sugar and starch are not the only kinds of foods manufactured by a plant. It also manufactures *proteins*, a food that contains carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur and phosphorus. These last three elements are taken in by roots of plants from solutions of certain compounds in the soil (nitrates, sulfates, and phosphates). Since proteins are necessary for plant and animal growth, roots perform a function necessary not only to all plant life, but also to the very existence of all animal life. In addition roots hold plants in position, preventing all usual winds from tearing them from the soil. Often the roots of a plant serve as storage places for the food manufactured in the leaf factories.

Experiment 144. To study the structure of a root. Cut a very thin cross section of the root of a young bean or other green plant and study it with the aid of a microscope. Make a drawing of the structure of the cross section, and describe it.

Stand the root of a carrot or parsnip in water colored with red ink and leave it there for about twenty-four hours. Then cut thin slices of the root, both crosswise (a cross section) and lengthwise (a longitudinal section) and examine each slice with a magnifying glass. What do you see?

Figure 314 is a diagram of the cross section of a root. The outer skin *b* is the *epidermis*. The cells under the epidermis form the bark *c*, *cortex*. The inner portion of the root, the *central cylinder d*, is composed of different kinds of cells. The long cells in the central cylinder serve as tubes through which water rises up to the stem. Other long cells or vessels carry food produced by the leaves down even to the growing parts of the roots. Other cells, with stiff walls, serve to strengthen and stiffen the root. In the center of the cylinder is a tube of *pith*.

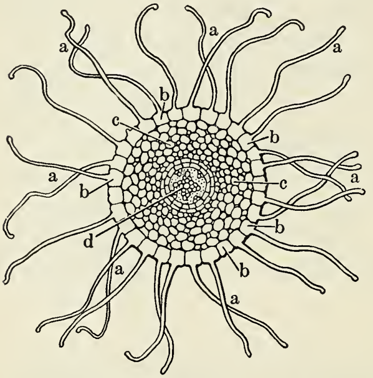


FIG. 314. Cross section of a young root, magnified.

At the tip of each tiny growing root, a group of cells on the epidermis forms a *root cap*. As the walls of these cells are tough, they protect the growing point of the root and enable the root to push the root cap ahead through the soil. The tip of each root is smooth but just behind this smooth tip is a mass of *root hairs*, *a*, projections from the cells that make up the epidermis of the root. It is through these root hairs that a water solution of minerals is taken into the root. As the root grows, the root hairs farthest from the tip die and new root hairs grow nearer the tip.

How do the root hairs absorb water and mineral solutions from the soil? The openings in the *cell wall* of a root hair are so small that they cannot be seen with the most powerful microscope; nevertheless they are large enough to allow the molecules of solutions in the soil to pass through them. Root hairs are surrounded by solutions in the soil which furnish raw materials for the leaf factories. These solutions pass into the root hairs by a process which the following experiment will help you to understand.

Experiment 145. To show how liquids pass through plant tissue. With a carpenter's auger bore out the inside of a medium sized carrot. Dissolve as much sugar as you can in a small amount of water and add a little red ink to color it. Fill the hole in the carrot with this solution and fit the hole with a one-hole stopper through which a glass tube has been run (Fig. 315). Support the carrot in a beaker containing almost enough water to cover the carrot. As the stopper is pushed down into the hole in the carrot, the red solution will be forced up the tube. Mark this height with a rubber band. If the stopper does not fit tight, it should be sealed with melted paraffin. Watch the red solution from hour to hour. What happens?

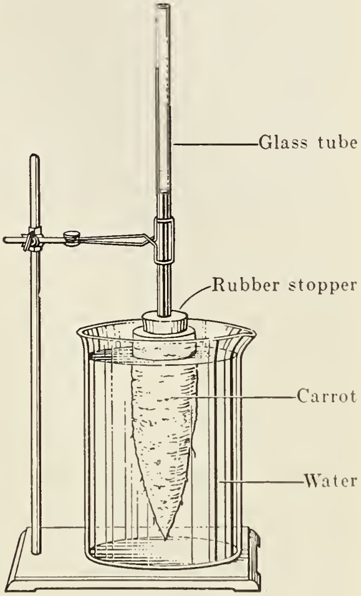


Fig. 315. By what process does the red solution rise in the tube?

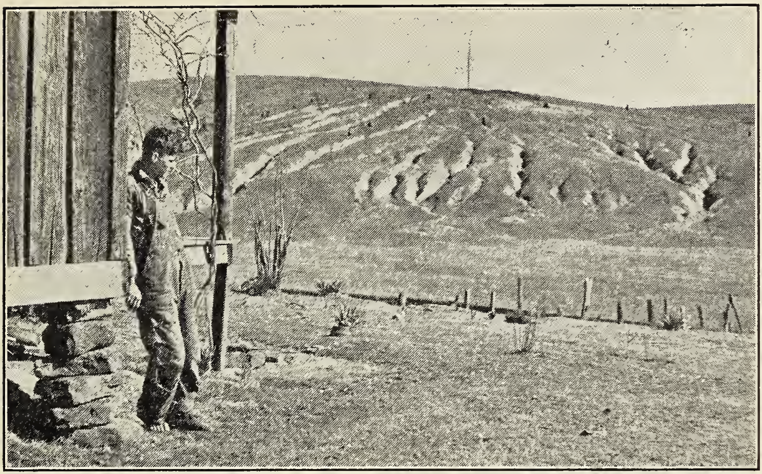
It is believed that the molecules in the water and the molecules in the sugar solution in the carrot are in rapid motion and are constantly striking against the carrot tissue. The molecules of water pass through the openings in the carrot tissue more easily than the molecules of sugar. This means, of course, that the water will pass through the carrot tissue more rapidly than the sugar solution will pass out through the carrot tissue. This causes the amount of sugar solution (liquid) in the tube to increase. This causes the liquid to rise in the glass tube. The liquid will continue to rise in the tube until the rate of flow of molecules into the carrot becomes equal to the rate of flow of molecules out of the carrot. Then the height of the liquid in the tube will be stationary. Why?

A tissue through which one kind of molecules pass (permeate) more readily than another kind, is called a *semi-permeable* tissue. The process by which liquids and gases pass through semi-permeable tissues is called *osmosis.* Always the thinner or less dense liquid or gas on one side of the semi-permeable tissue passes through faster than the more dense liquid or gas on the other side of the tissue. If water and molasses were separated by a semi-permeable tissue, which would pass through the the tissue more rapidly?

How do root hairs use osmosis? Each root hair is a living bit of protoplasm which contains water with sugar and other compounds in solution. This solution is called *cell sap.* The cell sap in the root hair is separated from the water in the soil by the cell wall of the root hair. This cell wall will not allow the sugar molecules of the cell sap to pass through as readily as the molecules of water and some solutions of plant food which are in the soil. These solutions pass by osmosis through the cell wall of a root hair into the root hair. In this way a plant secures food from the soil. This same process of osmosis permits these solutions to pass from cell to cell through a plant. By what process do you think air passes from one cell to another in the leaves of a plant?

Other functions of roots. Roots serve man in other ways than by securing materials from the soil which the plants use to manufacture the food on which we live. One of their most useful functions is partially to prevent soil erosion, that is, the wearing away of soil by wind and water. To give some idea of the harmful effects of erosion, we quote from a bulletin of the United States Department of Agriculture:

> "The largest man-made gulley in the Western Hemisphere lies 8 miles west of Lumpkin, Ga., and it is no credit to the United States of America whatever. It is 200 feet deep. The drip from a barn roof started it 50 years ago. Now that it has got its growth, it has swallowed the barn, a school house, a tenant house, and a graveyard. . . . Such erosion annually steals 3,000,000,000 tons of soil from our farms and pastures. This means a direct monetary loss to farmers of not less than $400,000,000 every year, showing up in reduced yields, abandoned land, damaged highways and reservoirs, and irrigation ditches and culverts choked with erosional debris."



Courtesy Soil Conservation Service

FIG. 316. In the background of this picture you see a badly eroded hillside. Tree stumps indicate that it was once covered with trees. Do you think there may be any relation between the eroded land, the boy's ragged clothing, and the unsightly home? How could this erosion be prevented?

Soil on hillsides and mountains is held together mainly by the roots of trees and other plants (Fig. 316). This soil and the covering layer of decaying leaves and other vegetable matter act as a sponge which holds water that falls as rain and snow. Water seeping down through such soils feeds springs, which are located usually at the bases of hills and mountains. If trees on hillsides or mountain slopes are cut down or destroyed by fire their roots soon decay. As a result rain and melting snow can easily wash the soil down into the valleys leaving the slopes bare. Since there is now no "sponge" to soak up the water, other rains result in great torrents of water rushing down the slopes, frequently causing destructive floods. When a hillside is washed bare of soil, springs dry up and neighboring streams grow smaller. History records the desolation of the Greek city Paestum, as the result of floods caused by the destruction of forests on the mountain sides. The rivers filled the harbor with mud, and disease germs developed in the pools of stagnant water. Scientists have stated that a similar situation might prevail in the city of New York, should the forests of the Adirondack and Catskill mountains be destroyed. Importance of the roots of trees and other plants in their relation to the rate of stream flow is often overlooked.

What causes roots to grow downward? Did you ever ask that question? One cause is gravity. There is another cause, however, that helps to determine the direction in which roots grow. The roots of a plant must furnish it with water and food if the plant is to live and grow. As a plant grows, its roots tend to grow to places where the supply of water is large enough to keep it in a healthy condition even in dry weather. The root surface of most trees is greater than the surface of the branches and leaves. Roots of alfalfa have been known to grow in deep porous soil to a depth of fifteen or twenty feet below the surface of the ground.

Problem: How Does the Stem Transport Materials Between Roots and Leaves?

A living tower, the stem. The stem of a plant has two main functions: (1) to support its branches and thus spread out its leaves to sunlight; and (2) to furnish a means of transporting materials back and forth between the leaves and roots. The stem of a tree increases in strength and size each year to take care of the ever-increasing weight of the branches and the ever-increasing amount of material which must be transported. The famous blue-gum trees of Australia and the Sequoias and redwoods of California have grown to a height of more than four hundred feet. How great a strain there must be upon the stem of one of these great trees when the wind blows! How vast an amount of material must be transported through the stem from the roots to the leaves! How fierce must be the struggle to grow up and up so that the leaf factories can get enough sunlight to keep the tree from dying of starvation! Can any man-made towers compare with these?

Experiment 146. To observe how stems transport liquids from the roots to the leaves of a plant. Cut off a small stem or branch of a tree, such as an elm. Place the cut end in a glass of water colored with red ink. On the following day remove the stem and cut through it. Does the colored water rise all through the stem or only in definite places?

The path followed by a liquid in a stem may also be seen by putting one end of a stalk of celery in colored water. Try tinting a white carnation by placing its stem in colored water. If the stem of the wild flower commonly called May apple is used when the plant is in bloom, the red ink shows through the transparent tissues of the stem and pink paths show in the flower.

These experiments show that liquids travel through certain very definite tubes or veins in stems. These veins are usually arranged in bundles, which occur as a ring near the exterior of the stems of some plants and which are scattered through the stems of other plants. These tubes are not hollow tubes like water pipes. They are made up of cells end to end and the solution passes from one cell to the next by osmosis.

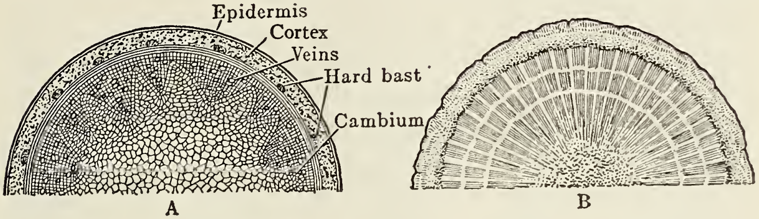


FIG. 317. *A*, cross section of a one-year-old stem; *B*, cross section of a three-year-old stem.

The structure of the stem of a tree. If you were to examine a cross-sectional cut of a young tree, such as a willow, you would find three very distinct regions. In the center is the soft, spongy *pith;* surrounding this is the rather tough *wood;* and on the outside is the *bark.*

A closer examination of the bark shows that it is made of three distinct layers—the epidermis, a middle layer of *cortex,* and an inner layer of tough fiber-like cells known as *bast fibers.* This inner layer of the bark contains the bast fibers and the tube-like structures which carry the food from the leaves down through the stem. Find these three layers of the bark on Figure 317A which shows the cross section of a young tree stem.

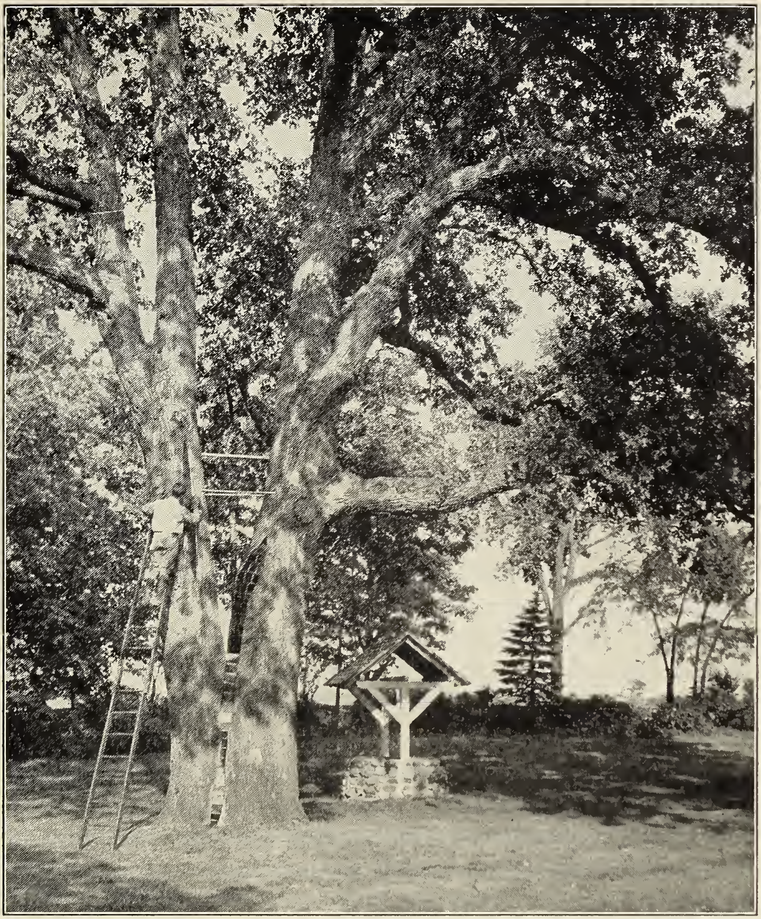
In *A* notice the points of pith extending out through the wood toward the bark and separating the wood into wedge-like sections. As the stem grows these are gradually compressed into thin plates of pith as shown in *B*. These *medullary rays*, as they are called, are made of cells whose functions are to store food and to form a means of communication between the outer and inner parts of the stem.

The masses of wood contain many cells which form little tubes, through which the food absorbed by the roots of the tree is transported to the leaves. Besides these tube cells there are other thick-walled cells which give strength to the wood.

What part of a stem grows? Just beneath the bark is a thin layer of actively growing cells, the *cambium* layer. This layer is very thin; even in a large tree it may not be more than an eighth of an inch thick. Yet it is the only actively growing part of the stem (Fig. 318). The cells in the cambium layer divide, as do the cells in any other growing thing; but the remarkable thing about these cells is that when those on the inner part of the cambium layer divide, the layer of new cells, called the "daughter cells" nearest the center of the tree become wood, and when the cells on the outer part of the cambium layer divide the layer of daughter cells which are nearest the bast become bast. The cells in the center of the cambium layer continue to be cambium cells. Each year the cambium layer adds a ring of wood inside and a ring of bark outside itself. Thus the trunk of the tree increases in diameter.

A stem increases in height by the growth of buds at the ends of the stem and branches; these are called *terminal buds.*

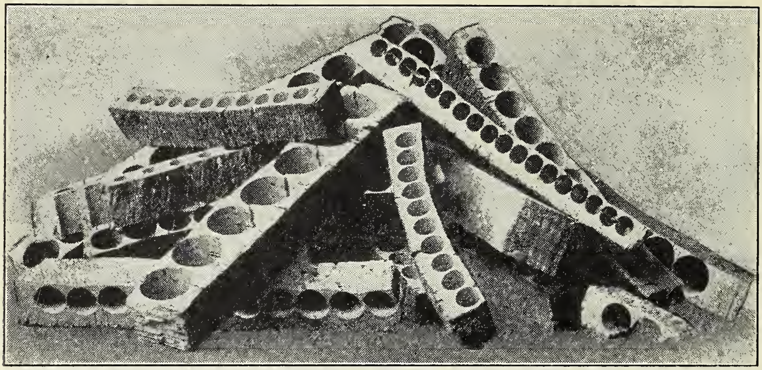
What causes the annual rings of growth? The growth of the cambium cells depends upon the amount of food brought to these cells. In the temperate zone the growth is most rapid in the spring. Food is abundant and the cambium cells form large, loosely arranged wood cells. During dry summer seasons food is not so abundant and the wood cells formed are more compactly arranged. During the fall and winter there is little or no growth. So a year's growth of wood consists of the spring growth of large, loosely arranged cells and the summer growth of smaller, com-



Courtesy The Davey Tree Expert Co.

FIG. 318. Beautiful trees such as this one take so many years to grow that we should preserve them. Since the only actively growing part of the trunk of a tree is the thin cambium layer, it is possible to remove decayed parts and replace them with cement.

pactly arranged cells. Together these form an annual ring. Figure 317B shows the stem of a young tree. Count the annual rings. How old is this tree? What effect do you think a very dry summer would be likely to have on the thickness of an annual ring?



Courtesy Armstrong Cork Co.

FIG. 319. Strips of cork from which corks have been punched.

How does cork grow? Just as there are annual rings of growth in the woody part of a tree, so there are annual rings of bark formed on the outside of the cambium layer. In Spain where bark is a commercial product (Fig. 319), the annual rings of cork around the stems of the cork oak form a comparatively thick layer. The outer cells of the bark are cut off by the cork from a supply of moisture and food and consequently die. This is the reason that the outer layers of bark on such trees as hickory and sycamore slough off.

How are trees killed by "girdling"? A tree that is "girdled" late in the season by cutting a ring of bark away from the trunk will continue to live for the rest of the season because water and minerals still continue to ascend through the wood cells. The next spring, however, when the buds burst forth into leaves and blossoms, and the young branches expand rapidly a large amount of food is required by the roots. But the tubes that transport food from the leaves to the stem and roots have been cut. Consequently the roots cease to perform their functions and the tree dies.

How does the stem of such a plant as corn differ in structure from the stem of a tree? You have learned that in the trunk of a tree, the bundles of tube-like cells that carry food from roots to leaves and from the leaves down through the stem are located near the surface of the stem.

Figure 320 shows a cross section of a corn stalk. Notice that the bundles of tubes are scattered throughout the stem. These bundles extend the entire length of the plant, from the roots to the leaves. The outside of the stem of the corn plant is a hard rind formed of large numbers of these bundles closely packed together. Much food is stored in the stems of plants like these—the sugar cane and the palm. Many other useful plants, such as grasses and grains, have the same kind of stem structure.

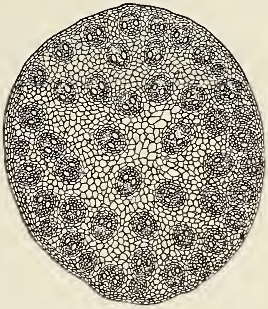


FIG. 320. Compare this cross section of a corn stalk with the stem of a young tree in Fig. 317, *A*.

PROBLEM: HOW CAN WE CHANGE THE KIND OF FRUIT PRODUCED ON A TREE?

Will a piece of a plant grow into a new plant? As you know, flowering plants reproduce by seeds. It is possible, however, to raise plants without sowing seeds. Have you ever seen your mother plant a "slip," that is, a stem or branch of a flowering plant? You may have seen a farmer or gardener cutting potatoes into pieces, being careful that each piece contained at least one bud, or "eye." From these pieces, new potato plants will grow. Currants, grapes, willows, cotton woods, poplars, and many other plants will grow from a slip. In some cases a leaf of a plant will do, but usually a stem is used. The growing of plants without the use of seeds is called *vegetative reproduction.* Other kinds of vegetative reproduction are *grafting*, *layering*, and *budding*.

Experiment 147. To show a simple kind of vegetative reproduction. Put a small branch from a willow, geranium, or English ivy into a jar of water for a few days. Examine the end of the branch that was under water. What has happened? Have any new leaves formed?

What kind of vegetative reproduction would you call this? A willow twig or branch stuck into the ground in the spring will grow into a tree. Why?

Can a twig or a bud be made to grow on another plant? Sometimes it is possible to improve the variety of fruit grown on a tree by *grafting* on to it a bud or a stem from a tree which bears a better variety of fruit. The two trees must be of the same species or nearly the same species. We could not graft an apple twig on to an elm tree.

Experiment 148. To learn how to graft a twig of one tree on another tree. Select a branch an inch or more in diameter on the fruit tree which is to be grafted and saw it off a few inches from the stem on which it grows. This branch is called a *stock;* the twig or bud to be grafted on the stock is called a *scion.* Prepare a scion by cutting the stem end of a twig into the shape of a wedge. Carefully split the end of the stock in the center, hold the split open and insert the scion (Fig. 321).

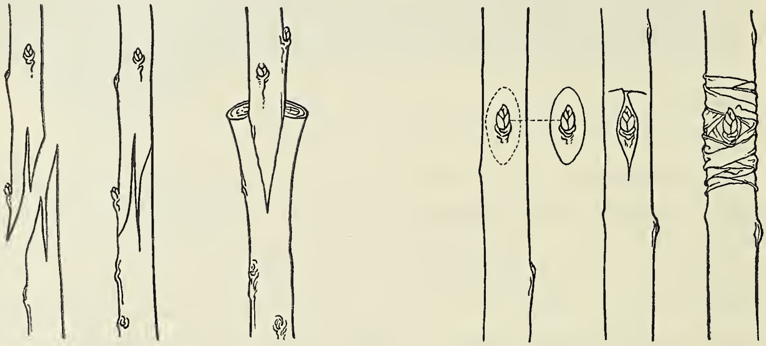


FIG. 321. Two ways of grafting. Let one member of the class show with actual branches how to prepare the stock and scion as shown at the right. Can you suggest reasons why grafting is sometimes unsuccessful?

Since the growing part of a stem is the cambium layer, be careful that the cambium layer of the stock and that of the scion come into contact. To keep air away from the union of the stock and the scion cover it with grafting wax, taking care that the end of the stock is completely covered to keep the stock from drying out. Observe the scion from day to day and report the results in class.

Usually grafting is done in the early spring. The scions should be cut some time previous to their use, and stored in a cool place. Although grafting wax can be purchased ready for use, you can make grafting wax from rosin, beeswax, and tallow, in the proportion by weight of four, two, and one, respectively.

Budding. Let us follow the steps in the development of a young peach tree. First, a seed (peach pit) is planted in the spring. The nurseryman will not sell you the seedling that grows from it because he cannot tell what variety of peach will come from the peach seed which he planted. In the autumn he selects a bud from a peach tree that he knows to be a good variety and grafts it into the side of the seedling near the root. To do this he makes a T-shaped incision in the bark of the tree (Fig. 321). The incision is made on the shady side of the tree, as near to the ground as possible. A single bud is cut so that it is attached to a portion of bark in the shape of a shield. The shield-shaped portion of the bark is then inserted into the opening. The bud is made secure in its new location by being wrapped with raffia or with yarn. The cambium of the bud should fit against the cambium of the stock. Why? The wrapping material is removed when growth begins and the next spring the stem on which the bud is grafted is cut off just above the bud and sealed with wax. Why do you think this is done?

Layering. Some plants such as the raspberry and rose can be reproduced by bending a branch to the ground and covering a part of it with soil. A new plant may start from each part of the branch covered while the branch is still a part of the main plant. After the branch has taken root it may be cut from the "parent" plant.

PROBLEM: WHY ARE FLOWERS NECESSARY TO PLANTS AND TO US?

In a landscape or the lawn of a city or suburban home, the green color of grass, shrubs, and trees is pleasing and restful to the eyes. Yet the picture is not quite complete unless we see flowers here and there among the green clusters. These not only afford us beauty, but as we study their structure and function we shall understand how necessary flowers are to plants themselves.

Special problem. Make a study of the landscaping of a city, suburban or country home that is thought to be beautiful. As you look at it try to discover what elements make it artistic. Then make a drawing showing the location of trees, shrubs, flower beds, hedges, lawns, walks and the like.

Experiment 149. To study the parts of a flower. Examine a flower (Fig. 322B), such as a snapdragon, sweet pea, buttercup, petunia, tiger lily, Easter lily, trilium, etc.

The very outside of the flower is the *calyx* (1), made of a set of green leaves, the *sepals* (1). Find them on the flower. How many sepals are there? Cut the calyx carefully from the flower. Some flowers, like the tulip, do not have a calyx.

Inside the calyx is the *corolla* (2). Its parts are called *petals* (2). These are often brilliantly colored and form what we usually think of as the flower.

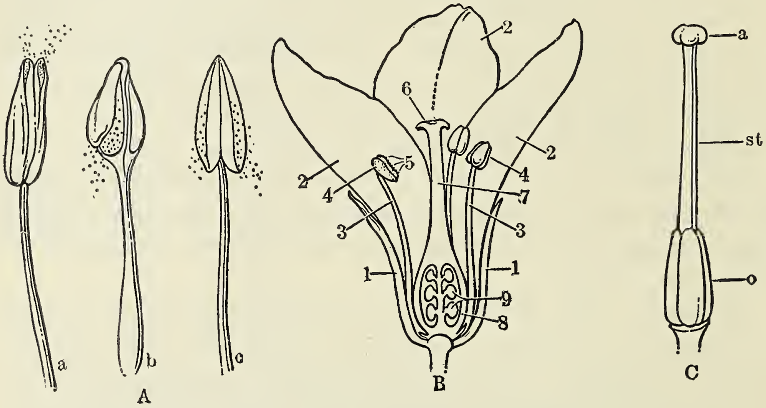


FIG. 322. In *B* are shown the parts of a complete flower: *a*, calyx (sepals 1); *b*, corolla (petals 2); *c*, stamen (filament 3, anther 4, pollen 5); *d*, pistil (stigma 6, style 7, ovary 8, ovules 9). In *A* are shown three stamens with different forms of anther: a, night-shade; b, barberry; c, gilly flower. In *C* is shown a simple pistil: a, stigma; st, style; o, ovary.

Find the corolla. How many petals does it have? The corolla of some flowers is all in one piece. Remove the corolla from the flower.

The remaining parts of the flower are sometimes called the essential parts because they are necessary for the development of seeds.

Now find the slender stems with enlargements at the ends. Each of these is a *stamen* (3); the enlargement at the end is the *anther* (4). When the anther is mature, *A*, it is covered with a powdery dust called *pollen* (5). Pollen is usually yellow in color. Make a drawing of a stamen and label the anther and the filament.

In the very center of the flower is a bottle-shaped part called the *pistil*, *C*. Find the pistil. The pistil in nearly every flower has three well-defined parts. At the top of the pistil is a small enlargement called the *stigma* (6). A slender stem, the *style* (7), connects the stigma with a thicker part at the base of the pistil, called the *ovary* (8). The style is not present in the flowers of some plants, such as the tulip. In other flowers the pistil may have a number of stigmas and styles. Make a number of cross sections of the ovary. The parts of the ovary are somewhat similar to the parts of a pepper. The little white round bodies in the ovary are called *ovules* (9). Into what will they develop? Make a drawing of the pistil, and label the stigma, style, and ovary.

Any one or more of the parts of a flower may be lacking in a flower. This is very apt to be true of cultivated plants because gardeners have interfered with their natural development in order to get more beautiful plants. In summer observe these cultivated plants to find out which of them have parts lacking.

Why does a flower develop pollen? Perhaps you are curious to know what becomes of the pollen grains that develop in the anther. After they are fully developed they start on a journey. A few of them may go only so far as to fall on the stigma of the flower of which they are a part; others may be carried farther away, by the wind, by an insect, or by other means to the stigma of another flower of the same kind. Pollen is carried by water and water animals from one water plant to another. You have probably had the experience of finding yellow dust on your clothes after you had walked through a patch of rag weed. This yellow dust is pollen. Can you suggest other ways by which pollen may be distributed?

The transfer of pollen from an anther to a stigma is called *pollination.* Pollen grains from the anthers of a plant may fall upon the stigma of the same plant. This kind of pollination is called *self-pollination.* If pollen grains from the anthers of one plant are transferred to the stigma of another plant of the same kind, *cross-pollination* has taken place. The anthers and stigmas of flowers, such as those of the pea, the iris, and the violet, are so situated with reference to each other that cross-pollination usually takes place. If you pull up a violet plant in the woods during the month of July you may find under the decaying leaves flowers with a whitish color. These plants are self-pollinated.

Why is pollination necessary?—Fertilization. Seeds develop through pollination. The ovules in the ovary of a plant will not develop into seeds unless fertilized. The pollen grain supplies what the ovules need to develop into seed. Each ovule contains a sack in which there are seven or eight cells. The most important of these cells is the egg cell. Each pollen grain when mature contains two sperm cells and one stalk cell. When a pollen grain falls on a stigma, the stalk cell develops into a pollen tube that grows down through the style (Fig. 323) toward the ovary and enters a little opening (micropyle) in one of the ovules. As soon as the tube reaches the egg cell in an ovule the tube bursts, setting free the two sperm cells which are in its tip. One of the sperm cells unites or fuses with the egg cell to form a cell that is able to develop into seed. This process is called *fertilization.*

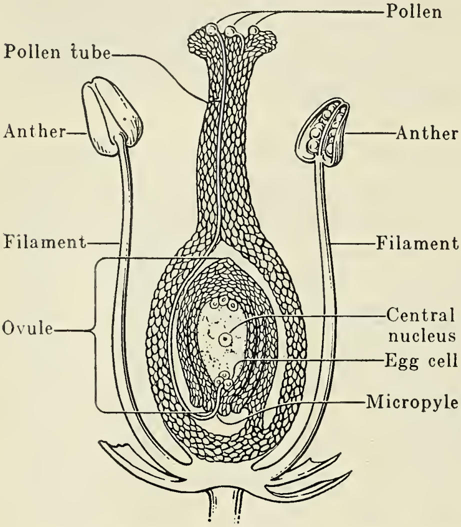


FIG. 323. Trace the stages of fertilization from the time a pollen grain falls on the stigma until the sperm cell fuses with the egg cell.

The development of a seed. The fertilized egg cell divides and becomes two cells; the two cells become four cells. What is this process called? At first the cells are exactly alike, but as they increase in number, different kinds of cells form. Many kinds of cells are needed by a plant. Leaves, roots, and stems are each made up of different kinds of cells.

The seed of a plant contains an *embryo,* a tiny plant which has for a time stopped growing. Under proper conditions of heat and moisture, it will begin to grow. A seed is composed of microscopic cells. Cells of many kinds of seeds contain starch grains. A cell may contain oil also. For example, there is enough oil in the cells of cotton seed, flax seed, and corn kernels to make it worth while to extract it for commercial use.

How do plants sow seeds? Figure 324 shows some of the ways by which seeds are scattered. Some seeds simply drop to the ground; the seeds of other plants fall into water and may be carried by the current for many miles. Coconuts have been known to float for miles down rivers or along shores. The seeds of other plants, like the orchid, are light enough to be carried long distances by the wind. Little feathery attachments on the seeds of dandelion, thistle, and milkweed enable the wind to carry them easily. Hold a maple seed high in the air and notice how it falls to the ground. The seeds of the sycamore, elm, and ash also have winged extensions which act as sails.

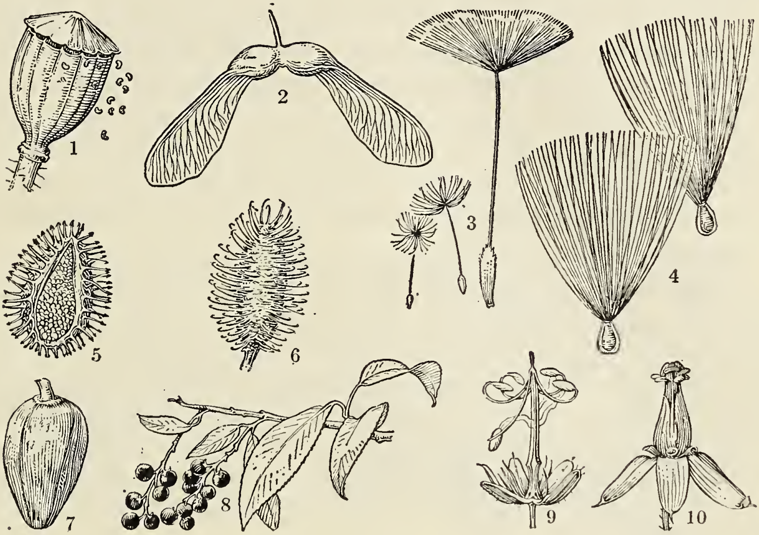


FIG. 324. Point out how the following kinds of seeds are dispersed: 1, poppy; 2, maple; 3, dandelion; 4, milkweed; 5, burdock; 6, cocklebur; 7, thistle; 8, bird cherry; 9, geranium; 10, erodium.

Some plants develop an elastic tissue which bursts open and throws the seeds out. For example, the fruit of the sand-box tree explodes and scatters its seed for some distance. A plant called the squirting cucumber has seeds embedded in a semi-fluid pulp. When the fruit is separated from the plant, seeds are forced through an opening near the base of the fruit for some distance in much the same way that water is forced out of a squirt gun.

Tumble weeds and other plants which break off at the surface of the ground may be blown long distances, scattering seed as they go. The barbs and hooks on the seeds of other plants cling to the fur or wool of passing animals and to the clothing of man, and the seeds may be carried for miles. Many different kinds of seeds are eaten by birds and other animals and in consequence many different kinds of plants are distributed widely over the earth.

Experiment 150. To study the parts of a seed. Soak several lima beans over night. With a sharp knife loosen and remove the protective covering from one of the beans. Now run the knife blade along the edge of the bean until it splits apart. From one half remove the embryo with care and observe the tiny leaves and sturdy-looking root. In seeds of some plants it is rather difficult to distinguish the leaf and the root of the embryo from each other. Place a drop or two of iodine solution on one of the halves of the bean. What color does the bean turn? When iodine is placed on a substance containing starch it turns a dark blue color. Did the bean contain starch?

Cut a thin slice from an unroasted peanut and place it under the microscope. Mount in water and look for the minute oil globules within the cells of the seed.

What conditions are necessary to germinate a seed? The development of a plant from a seed is an extraordinary process. Seeds kept in a dry place may remain dormant for years, but if placed under favorable conditions they begin to grow. The early stages of seed growth are known as *germination.* The seed itself will not start to germinate unless supplied with moisture and warmth. The amount of moisture needed for different kinds of seeds can be determined only by experiment. Some kinds will start growing when completely covered with water; others will not.

Another factor in the growth of a seed is heat. You probably have learned from experience that some kinds of seeds begin to grow earlier in the spring than others, i.e., at a lower temperature than others. Most kinds of seeds germinate at a temperature between 60° and 80° F.

Experiment 151. To watch the germination of a seed. In a box filled with moist soil plant a dozen or more lima beans. At the end of each day take up one of them and examine it. In this way you will observe the various steps in the germination of a seed.

One of the first changes you will observe in the bean is the breaking of its skin (*testa*). Next you will see a sprout pushing out through the broken testa to form a stem and roots. Soon you will notice the stem pushing the two halves of the bean up out of the soil (Fig. 325). This growth causes an arch in the stem which straightens out as soon as the bean seed is well out of the ground. The two halves of the bean, called *cotyledons*, furnish food needed by the new plant before its roots are able to get food from the soil. Before the cotyledons are used up the roots begin their work. As the food in the bean seed is used up the cotyledons wither away and fall to the ground and from then on the roots supply food. Between the cotyledons you will find the first true leaves. The root by this time goes downward rather rapidly and sends out branches in all directions to gather food for the new plant.

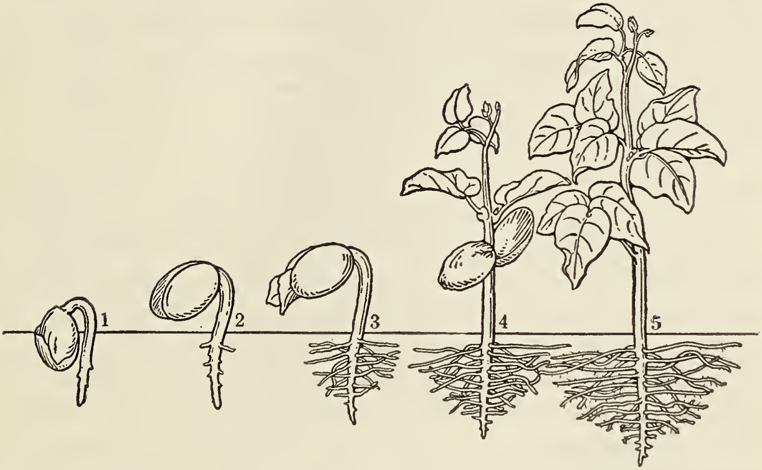


Fig. 325. Five stages in the growth of a bean plant. Note how the seed comes out of the ground, how the seed leaves are formed, and how the seed leaves wither when the leaves and roots are sufficiently developed to furnish food by the process of photosynthesis.

Experiment 152. To show that heat is generated and given off by germinating seeds. Place soft wet paper to a depth of one inch in the bottom of two drinking glasses, into one glass put beans or peas that have been soaked in water. Place a thermometer in each glass and let the glasses stand side by side. At the end of a day or two compare the two readings. In which one is the temperature the higher?

This experiment teaches us that, although heat is necessary to start germination, germination also generates heat. The heat generated and given off by germinating seed is due to oxidation, just as heat is generated by the oxidation of coal and wood. The seed, therefore, requires oxygen for its germination. Where does it get its oxygen? Like other living bodies a germinating seed gives off heat and carbon dioxide as products of oxidation.

All stages of growth, from the sprouting of a seed until the young plant can take care of itself by gathering its own materials and preparing its own food, are known as the *stages of germination.*

How do we classify plants? The number of cotyledons in a seed furnishes us with a means for classifying seed-bearing plants. Such plants as corn and other grains grow seeds that have one cotyledon only. Plants that produce seed having but one cotyledon are called *monocotyledons.* The monocotyledons are very abundant and produce many of man's necessities. Only a few of them are trees, such as the palm tree. Most of them are smaller plants like trilliums and orchids. Most of the early spring flowers that come from bulbs like the daffodils, hyacinths, tulips, and lilies are monocotyledons; so are the grasses, including the grains.

Monocotyledons have other features which help us to distinguish them. The bundles of veins in their stems are scattered. Usually the leaves are parallel-veined. The flower of a monocotyledon is usually either in three parts or a multiple of three: e.g., the lily has three sepals, three petals, and six stamens.

You observed that the bean seed had two cotyledons. Plants whose seeds have two cotyledons are called *dicotyledons.* Many of our garden vegetables, such as beans, peas, beets, and squash; many familiar trees, such as the maple, oak, chestnut, birch, and hickory; and practically all of our fruit trees, such as the apple, pear, peach, and plum, are dicotyledons. The bundles of veins in their stems are usually in a ring near the surface. The veins in the leaves of dicotyledons, such as the rose, violet, snapdragon, and pea, form a network. The flower of a dicotyledon usually is divided into four or five sections of each part.

Seeds of such trees as the fir, the spruce, the hemlock, and other members of the pine family usually have several cotyledons and for this reason are called *polycotyledons*, from "poly" meaning "many."

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

anther
bast
budding
calyx
cambium
cell
chlorophyll
compound leaves
corolla
cortex
cotyledon
embryo
epidermis
fertilization
filament
germination
grafting
layering
medullary rays
micropyle
node
nucleus
osmosis
ovary
ovules
organ
organism
palmate-veined
petals
petiole
photosynthesis
pinnately veined
pistil
pith
pollen
pollination
protoplasm
scion
sepals
stamen
stigma
stomata
style
tissue

Write the number of each item on your paper and after it the word that completes the statement.

1. Living matter is made up of small units called __________.

2. Living matter grows by the division of __________.

3. The raw materials from which food is made in leaves are mineral matter, water and __________.

4. The by-product from this manufacturing process is __________.

5. The stamens of a flower produce __________.

6. Seeds develop in the __________ of a flower.

7. The union of a sperm cell with an egg cell is ________.

8. The roots of a plant absorb water by the process of ________.

9. A leaf which contains a midrib through the center with branches on either side is said to be: palmately; parallel; vascular; feather-like; pinnately veined.

10. The process by which starch and sugar are produced in leaves by sunlight is called: osmosis; photosynthesis; diffusion; oxidation; fertilization.

11. The part of the pistil in which the seeds grow is called the: stigma; style; filament; ovary; anther.

12. The early stage of growth of a seed is known as: seed dispersal; pollination; germination; vegetative reproduction; planting.

13. Diffusion of a gas or a liquid of different densities through a porous membrane is called: osmosis; suction; fertilization; separation; concentration.

Which of these statements are true? If any are false, re-state them in correct form.

14. Inorganic matter is called protoplasm.

15. Living matter is made up of cells.

16. All plants have green leaves.

17. The parts of a flower necessary for reproduction are the stamens and the pistil.

18. The growing part of a woody stem is called the cambium layer.

CHAPTER XXVII

WHAT MATERIALS DOES MAN GET FROM PLANTS?

Do you know:

That plants are the food factories of the world? How Luther Burbank produced many new plants? That in some plants part of the flower develops into fruit? How the grain in wood is produced? That much of our clothing is made from materials produced by plants? That some kinds of silk stockings are made from wood?

How the smooth riding of automobiles depends upon certain plants? That the seed of an apple may produce a tree which will bear another kind of apple? That some foods are the seeds of plants? That some plants produce seeds only every two years? How some trees give an accurate story of each year of their life? That different kinds of wood vary greatly in hardness? Some trees produce "hard" wood and others "soft" wood. That cellophane is a very close relative of artificial silk?

Problem: What Foods Do Man and Animals Get From Plants?

Plants are the food factories of the world. All foods except a few minerals and water come directly or indirectly from plants. Sugars, syrups, spices, as well as vegetables, fruits, nuts, and grains, are obtained from plants. You know that those animals which supply us with most of our meat and with our dairy products feed entirely or nearly so upon plants or upon plant products. We eat the leaves of some kinds of plants, the fruits of others, the stem or the roots of still others, and all the parts of a few kinds.

Food furnished by leaves. Leaves form a valuable part of man's food. They are rich in minerals and vitamins and afford the bulky material or roughage needed in a well-balanced diet. Some plants whose leaves are used as food are lettuce, cabbage, spinach, and chard. What others can you name? Besides these, there are many other plants whose leaves are used for seasoning and for making beverages. The leaves of wintergreen and mint yield flavors used in confectionery. A pinch of dried leaves from the tea plant in a pot of hot water furnishes a beverage known throughout the civilized world.

Food furnished by fruits. At first man gathered fruit from trees that grew wild. Then he began to cultivate the wild fruit trees and vines, that is, to dig about them, to trim off useless branches, to transplant them to places where soil and climate were more favorable for their growth, and to group the trees in orchards to make it easier to care for them and to pick the fruit. Cultivation improved the size and flavor of many fruits; but the chief factor in the development of fruits was, and still is, the selection of seeds from superior plants to use in planting new orchards. The quality of fruit is improved also by *hybridizing*, sometimes called *crossbreeding*, brought about by cross pollination; for example, pollen from the flower of one variety of apple is placed on the unpollinated stigma of the flower of another variety. The stigma is then protected from further pollination by cutting away the petals which attract insects or by covering the blossom with a paper bag. After many trials an improved type of fruit is frequently secured. Luther Burbank produced a "white" blackberry, a hybrid fruit, by crossbreeding a plant bearing pale yellow berries with one bearing large black berries.

In the United States, with its many different soils and climates, a wide variety of fruits is produced. With few exceptions, every kind of fruit seen in our markets including figs, pineapples, oranges, grapefruit, lemons, and even dates and olives is raised within our borders.

Experiment 153. To observe what part of the flower develops into an apple. Divide an apple into halves by cutting through it halfway between the stem and the blossom end. Observe the several divisions in the core. These are the parts of the ovary of the flower from which the fruit developed.

The pepper, the tomato, the gooseberry, the cucumber, and the melon are each the enlarged ovary of the blossom, the wall of the ovary having become fleshy and juicy. The bean pod, too, is simply the enlarged ovary of the bean blossom. Name other fruits and explain how each has developed from the ovary of the blossom.

In fruits with pits, like the peach, plum, and cherry, the ovary wall develops into two layers. The inner layer becomes the hard stone that surrounds the seed; the outer layer becomes fleshy and juicy. Nuts as well as grains are fruits.

Plant stems as food. The stem of a plant enables the leaves and the roots to pass food back and forth from one to the other. Soil water that passes into the root hairs from the soil is transported through the stem to the leaves. These stems, as you know, are made up of cells which are arranged in such a way as to form tubes through which the food can pass. The bundles of tubes which make up the main stem divide and subdivide, extending out to each twig, where they subdivide and branch out into the leaf to form the veins. Food manufactured in the leaves is also transported to all parts of the plant through tubes in the stem and finally reaches the roots and even the root hairs themselves. These bundles of tubes, or fibers, are very noticeable in the leaf stalks of celery and plantain. They may make the celery "tough" and cause it to string when we bite into it. When we eat the stem of a plant, we capture part of the water and salts that were on their way from the roots to the leaves. We are also getting some of the food that was on its way from the leaves to the roots. Name several plants whose stems furnish food for man.

Certain kinds of plants develop underground stems known as *tubers*, of which the white, or Irish potato, is an example. What others can you name? Tubers are "storehouses" in which certain plants store food for their own use later or for that of man and animals.

Roots as food. Many plants store food in their roots instead of in underground stems. Plants such as turnips, beets, parsnips, and carrots that grow from seed do not blossom the first year. During this first year the plant grows and manufactures food which is stored in the roots. If roots of such plants are to be used for food, they should be gathered at the end of the first year of growth. During the second year, although little foliage is grown, the plant blossoms and produces seed, using up in this process most of the food stored in the roots. Can you tell why?

It has been stated that plants are the food factories of the world. In eating the leaves of a plant, like lettuce, we devour some of the very sources of our food supply, the factories themselves. When we eat the leaf stalk of a plant, such as celery, we are consuming raw materials on the way from the roots to the factories, and also the finished product made by the leaves on its way to the storehouse. And when we eat roots, such as turnips, and sweet potatoes and tubers, such as potatoes, we consume the finished product that has been stored by the plant.

PROBLEM: WHAT OTHER USE DOES MAN MAKE OF PLANTS?

Plants furnish the raw materials used by many industries in making products of commercial value. The raw material used in the manufacture of furniture and frame buildings is lumber. Foods, medicines and other products are manufactured from leaves, bark, roots, and sap. Trees, then, provide many raw materials, and we shall study these raw materials first.

Types of lumber. When a tree grows in a thick forest, branches along the lower part of the trunk die from lack of sunshine and drop to the ground. Thus the lower part of the trunk of the tree may have no branches for many years of the tree's growth. Lumber obtained from such tree trunks is usually free from knots and is called "clear." The part of the trunk near the bark, where the sap was flowing at the time the living tree was cut down, contains traces of this sap layer and lumber made partly from it is classified as *sap lumber*. Sap lumber can be identified by its bluish color and by the sap stains on the boards. Sap wood is not so durable as the center wood, the "heartwood," of the tree.

What causes knots? Knots in a tree trunk result from the growth of branches. A leaf bud is connected with the wood of the stem by fibers. As the bud develops into a branch, these fibers increase in number and the branch develops until it has all the layers of the trunk itself, bark, cambium, wood, and pith. This new stem extends across and interrupts the annual rings of growth on the main stem, causing the rings of the main stem to be curved into various shapes and to be pressed together tightly (Fig. 326). If the branch dies, the scar becomes covered by the normal growth of the tree and what is left of the branch within the trunk cannot be seen until the trunk is cut open. Lumber from a trunk which contains traces of former branches, as well as lumber from one from which branches are growing at the time the tree is felled, will have knots in it. If the wound left when a branch dies heals rapidly and is covered by the annual rings of growth, the knot thus formed will probably be solid and hard as the wood surrounding it; in fact, it may be even harder. Such knots do little damage to lumber.

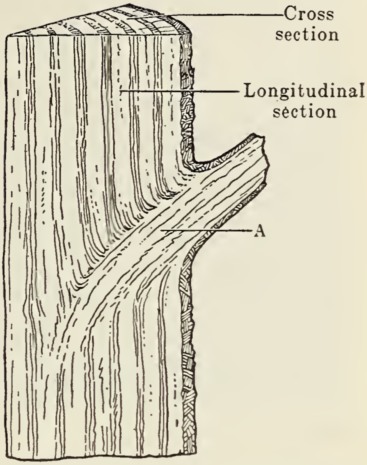


Fig. 326. A knot develops because a branch, *A*, extends across the annual rings of growth.

Seasoning lumber. As soon as a tree is cut down, the water contained in its cells begins to evaporate and the wood starts to shrink. Because of this, lumber is *seasoned*, that is, given time for evaporation to take place before it is used. Lumber is often seasoned by stacking it outdoors in huge piles through which the air can circulate; sometimes it is placed in rooms called kilns through which hot air is forced to hasten the seasoning process. Name at least two reasons why lumber should not be used unless it is well-seasoned.

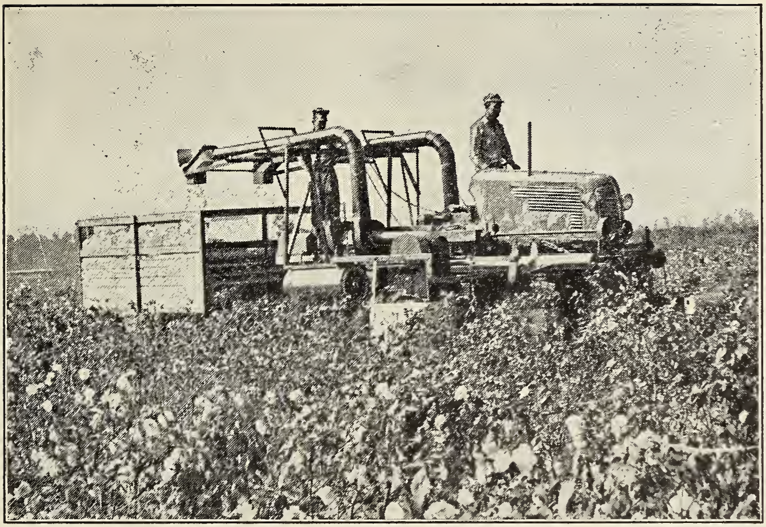
What causes a board to warp? If all the cells in a board were the same size and shape, and if they all extended in the same direction, the shrinking of lumber would not inconvenience builders much. But some cells are large; some are small; some have thick walls; others have thin walls; some run lengthwise; others, like the medullary rays, run from the center. Furthermore, the shrinkage is in the cell wall; the inside of the cells shrinks lengthwise very little, if any. Also, thick-walled cells shrink more than thin-walled cells. Consequently, as a board dries, there is a tendency for the side nearest the bark, where the thick-walled cells are, to shrink faster than the other side. This causes the board to curve, or as we say, *warp*.

Furthermore, even well-seasoned boards may warp if they are exposed to moisture. Rapid changes in temperature and amount of moisture, such as a board is exposed to when it lies out in the sun and rain, will cause it to shrink unevenly and to curl. Have you noticed the warping in the wood in houses near the sea or a lake?

Hard and soft woods. Wood from broad-leaved trees such as oaks, maples, and chestnuts, is known as *hard wood,* while that from cone-bearing trees (conifers) such as spruce, cedar, and pine, is called *soft wood.* This classification does not mean that all wood from hard wood trees is harder than that from soft wood trees, for the wood from some broad-leaved trees, like basswood and poplar, is softer than that from conifers like Georgia yellow pine. The terms "hard" and "soft" as applied to woods are relative terms only, since different kinds of wood vary widely in hardness.

What raw materials for clothing are obtained by man from plants? We have formed some idea of how dependent we are upon plants for food and shelter. If we now consider whether we are dependent upon plants for clothing, we shall discover that many *textiles,* that is, fabrics manufactured by weaving, are made from fibers of plants.

Cotton, the king of the South. Of all plant fibers, cotton is the one most widely used in the manufacture of textiles. Since cotton requires a long growing season in which to mature, it is raised only in rather warm climates (Fig. 327). The fiber is an outgrowth from the outer coat of the cotton seed. If the seed were permitted to ripen undisturbed, these fibers would help the seed to be scattered by the wind. A cotton fiber consists of long, twisted



Wide World Photo

FIG. 327. A mechanical cotton picker in operation on a farm in Louisiana. The cotton is planted in rows; until recently the only method of picking cotton has been by hand. Cotton fibers are spun as shown in Fig. 232.

filaments well adapted for spinning. Cotton is used in the manufacture of various products, such as clothing, tents, bed clothes, fabric for automobile tires, and a host of others.

From the cotton seed, a valuable oil product is obtained which is used in the manufacture of oleomargarine and other substitutes for butter and lard, and in the making of soap. The meal which is left after the oil has been extracted is pressed into cakes and used as food for cattle. Nitrocellulose, a substance made from cotton, forms the basis of celluloid, from which buttons, combs, toys, and the like are made. Collodion, a solution of nitrocellulose in ether and alcohol, is used in making guncotton and artificial silk. Collodion is also used in such products as liquid nail polishes and liquids used to form a protective coating for cuts and the like.

Linen, the coolest of fabrics. Linen fibers are obtained from the stem of the flax plant. After flax is cut, the stems are allowed to lie under water for a while; here bacteria cause the delicate cambium cells to decay, thus permitting the separation of the fibers from the rest of the stem. The fibers are cleaned and combed out. In the processes which follow—the spinning of flax into linen thread, the weaving of linen thread into cloth, and bleaching the cloth—many kinds of linen cloth are produced, varying from the exquisitely fine white linen from which the best quality of linen handkerchiefs are made to the coarse brown linen sometimes used for couch covers and art embroidery work.

Jute, hemp, and manila fiber. A number of other plants, with fibers coarser than those of cotton or flax, are also useful to man. Jute, the fiber of certain plants of India, is used in making burlap, twine, and the coarse bags commonly called "gunny sacks." It is also used in rug making. Hemp, raised both in our country and in other parts of the world, produces another fiber from which sailcloth and ropes are made. Manila fiber, obtained from the leaves of a plant found in the Philippines, is manufactured into a fine quality of rope and binder twine, and into bagging and sailcloth.

Silk, natural and artificial. Natural silk comes from the cocoons spun by silkworms which feed on the leaves of the mulberry tree (page 583). Artificial silk (rayon) is, however, a plant product. Rayon is often made of wood. The pulverized wood is treated with chemicals until the material is a fairly thick liquid. The liquid is then forced through tiny holes about 0.004 inch in diameter and hardened into flat, ribbon-like threads which may be spun into cloth. Cotton waste and other vegetable products may be used in place of wood in the manufacture of rayon. Rayon is dyed successfully in colors of great beauty. In a recent year 144,350,000 pounds were manufactured in the United States. In the same year the amount manufactured in the entire world, including the United States, was 467,550,000 pounds.

Cellophane, the universal wrapping paper. Have you ever wondered what this shiny transparent substance used to wrap candy, clothing, food, furniture, and almost everything we buy is made of? Of course you know it is called *cellophane*. It is a very close relative of rayon. Cellophane is made from exactly the same substances and in exactly the same way as rayon except that instead of the liquid being forced through small holes it is forced through a narrow slit. This makes the thin sheets of cellophane which we have come to know so well. It is supplied in large rolls to manufacturers who use it for wrapping merchandise. Cellophane is now produced which can be woven into a kind of cloth. The cloth is suitable for making rugs and for upholstering furniture. New uses for this substance are found almost daily and it is one of the valuable plant products of our modern life.

How is paper made? Most kinds of paper are manufactured from wood, particularly from hemlock and spruce. After sawing a tree into short lengths, the bark is removed and the wood cut into small chips. The chips are placed in retorts and heated, either in a solution of sodium hydroxide or in calcium acid sulfite, to remove impurities. The resulting material, cellulose, is bleached with chlorine and washed with water. The cellulose thus prepared is called *paper pulp*. The pulp is placed on screens, to allow most of the water to drip out. It is then run between heated rollers which press and dry the pulp, delivering it in the form of white paper. Often it is pressed between layers of felt to complete the drying process. Various grades of paper are produced by adding different materials to the pulp. For example, a small amount of clay is added to serve as a filler and give a smooth surface.

Much wood is now being used for this purpose. It is estimated that a certain newspaper in our country with a large circulation requires two thousand acres of forest a year to supply the pulp needed for its paper. Cotton waste, linen, and jute are also materials from which paper can be made. Fine grades of writing paper are made from linen rags mixed with wood; manila paper is made from a mixture in which manila fibers are used. Recently a method has been developed to make paper from cornstalks and it is believed that in the future much paper will be made in this way.

What is rubber? Rubber is the product of a tree (hevea) which grows wild in the upper Amazon region, and which is now cultivated extensively in several other parts of the tropical world. Large American manufacturing interests have established great rubber plantations in Sumatra, Liberia, Brazil, and Central America.

From long gashes cut in the bark of these trees, there flows a milky juice called *latex*, which is collected in cups hung on the trees, transferred to pails, and carried to the factory. This latex consists of water in which little particles of raw rubber are suspended, just as tiny particles of fat are suspended in fresh milk. Like milk, latex can be thickened by adding acid. Acetic acid is used most widely for the thickening process (coagulation). Latex may be secured from several hundred different kinds of trees and shrubs.

How is rubber prepared for use? In its pure state rubber is useless because it is sticky and easily affected by changes in temperature. It was a long time before any way was found to make rubber of practical use. But in 1839 Charles Goodyear of Connecticut discovered that, if rubber was heated with sulfur, it lost its stickiness and was no longer affected by changes in temperature. This process of heating rubber with sulfur is called *vulcanization.* Other materials, known as fillers, are mixed with the rubber to add strength, to give the product a certain color, or to bring out some other desirable quality. The reddish color of certain rubber goods may result from the use of antimony sulfide or iron dioxide as a filler. The black color of automobile tires is due to the use of carbon or lamp black as a filler. Rubber is a hydrocarbon, that is, it is composed of hydrogen and carbon. Chemists can make from carbon and hydrogen a material called *synthetic rubber*, which is like natural rubber in its properties. The process is too expensive, however, to make the preparation of synthetic rubber practicable.

What other raw materials do we get from plants? Among other raw materials obtained from plant life, we have already noted cork from the bark of the cork oak, which grows quite extensively in southwestern Europe. Cork is used in making stoppers for bottles and in certain kinds of linoleum; it is used also to make certain kinds of artificial limbs. Do you know any other uses of cork? What property of cork makes it useful in life preservers?

From pine and spruce we get excelsior (curled shreds of wood) used for packing articles easily broken in shipping. From cedar wood lead pencils are made. Bark from certain trees, especially oak and hemlock, is used in tanning leather. We also use the heartwood of a South American tree, the quebracho, in tanning.

Before it was known how to make dyes from coal tar products, many dyes were obtained from plants. The leaf juice of the indigo plant, one of the oldest and best of dyes, gives a blue color. As late as 1897 nearly a million acres of land were used to grow the indigo plant. But because of the abundance and cheapness of dyes obtained from coal tar products, the great indigo plantations have been abandoned. What other plants can you name from which dyes were obtained?

Many distilled products, such as wood and grain alcohol, acetic acid, bay rum, camphor, Arabic gums, and witch hazel are obtained from plants. Drugs such as quinine, opium, cocaine, and strychnine also are made from plants.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

burlap
cellophane
clear lumber
collodion
cross breeding
guncotton
hard wood
hemp
hybridizing
jute
knot
latex
manila fiber
nitrocellulose
pulp
rayon
sap lumber
soft wood
synthetic rubber
textiles
tuber
vulcanization
warp

Write the number of each item on your paper and after it the word or phrase that completes the statement.

1. A carrot is a plant whose ________ is used for food.
2. Celery is a plant whose ________ are used for food.
3. The sweet potato is an example of a plant whose ________ is used for food.

4. Lumber that is comparatively free from ________ is called clear lumber.

5. The evaporation of water from lumber is called ________.

6. The most useful plant fiber for making textiles is ________.

7. The black color of certain rubber goods is due to the element ________.

8. A knot in a board is caused by: a twist of a limb; abnormal growth; a hard substance under the bark; the growth of a branch; a rupture of the bark.

9. Linen is made from: manila fiber; cotton; hemp; rayon; flax.

10. A white potato is an example of: a root; underground stem; petiole; starch grain; bulb.

Which of these statements are true? If any are false, re-state them in correct form.

11. Many of the minerals used by the body are produced by plants.

12. Fruits are necessary to certain plants so that the seeds will be scattered by animals.

13. Knots in lumber may be made to produce beautiful grain effects.

14. Linen cloth is made from the cotton plant.

15. Rayon is made by silkworms.

CHAPTER XXVIII

WHAT ARE SOME OF THE LOWER FORMS OF PLANTS AND WHY IS IT NECESSARY TO PROTECT USEFUL PLANTS?

Do you know:

That plants, like people, contract diseases? That a plant is killing the chestnut trees in the United States? That there are many plants so small that they can be seen only with the aid of a microscope? That plants produce the vitamins in cold liver oil? That the mold on a piece of bread is a plant?

That some plants do not have flowers? That some water plants look like long green threads? That some plants are practically smothered by other plants? That certain plants are used in baking bread? That some plants form a green carpet among the trees in a forest?

PROBLEM: DO ALL PLANTS PRODUCE SEED?

So far we have considered only flowering plants, that is, plants that produce seed. Now we will consider non-flowering plants. Although they do not bear flowers nor produce seeds they are able to reproduce their kind. Some of these plants are composed of a single cell which performs all the functions of a plant such as absorbing food, growing, and reproducing its kind. Reproduction in such plants takes place by the division of the single cell into two cells, thus forming two single-celled plants.

Other non-flowering plants are reproduced by *spores*, tiny bits of protoplasm that possess the ability to grow into a new plant. For convenience in study, the non-flowering plants are classified into four groups: (1) algae, (2) fungi, (3) mosses, (4) ferns.

Algae, plants in unexpected places. Have you ever noticed green patches on the walls of old stone houses or on the trunks of trees? Secure a piece of bark covered with this green material and examine it under a magnifying glass or a microscope. What do you see? This green material is composed of many tiny plants, each of which is a single cell. These are one kind of algae. As the green color is due to chlorophyll, we know that these plants can manufacture their own food.

Algae in fresh water. The green scum that floats on stagnant water is thought by many people to be unclean, but it is not unless the water itself is unclean. One of the commonest plants in this scum is *spirogyra,* the most beautiful of the algae. The cells of spirogyra are joined end to end, forming long threads. The spirogyra plants are heavier than water, but the bubbles of oxygen formed as the plants manufacture food by photosynthesis cling to the masses of threads of spirogyra and cause the plants to float.

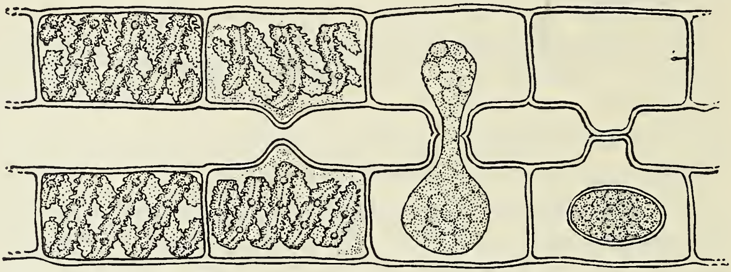
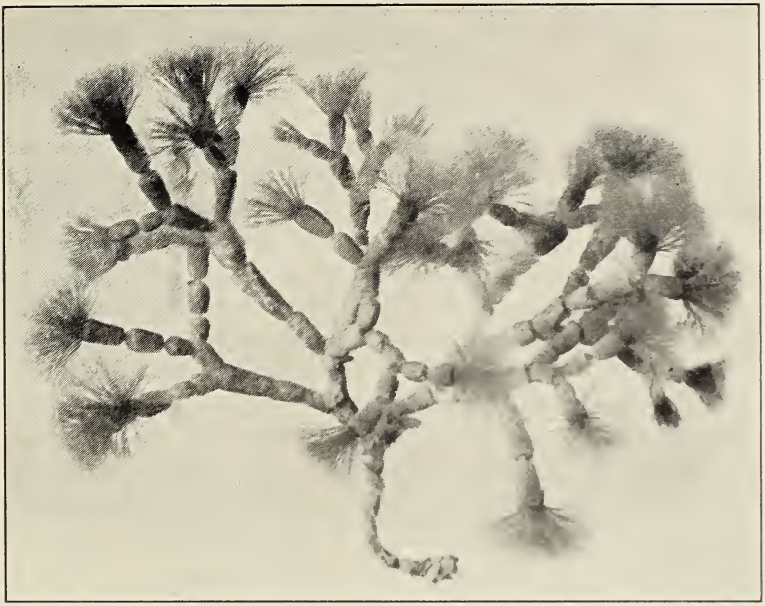


Fig. 328. Cells of green pond scum, spirogyra, in successive stages of reproduction.

Spirogyra grows by cell division; it also reproduces itself by spores, formed by the growing together of two cells to form one cell. In Figure 328, notice the projections from the second pair of cells. Two such projections may join, as has happened in the pair of cells directly to the right. The cell wall is absorbed so that a tube is formed between the two cells. The contents of one cell flow through this tube and unite with the contents of the other cell, forming a spore, as at the extreme right. A spore cell differs from an ordinary cell in that it may remain without growing (dormant) for some time and will also live through much hotter and much colder weather than other cells of spirogyra. Thus one of these plants may die off in the fall of the year, but the spores which it has produced live through the winter without



Courtesy William Beebe

FIG. 329. One of the many kinds of seaweed. Notice the delicate filaments. This seaweed is so light that it keeps near the surface of the water where it can receive sunlight.

any growth, and in the spring when temperature and moisture conditions are favorable will develop and grow into complete plants.

The green, threadlike growth found on rocks in fast running water and on pebbles along the shores of lakes where waves beat is another of the algae. The green cells of this kind of algae are a source of vitamins. Of course we do not eat these algae, but fishes do, and thus indirectly we obtain vitamins from these algae.

Algae in the sea. The coarse brown seaweed found lying along the shore of the sea is one of the brown algae. So much of this seaweed grows in some harbors that it interferes with navigation. Iodine is extracted from these brown algae. Other seaweeds (Fig. 329) are also a form of algae. The colors of different kinds of these algae range from red to purple; sprays of these plants floating on the water are often very beautiful.

PROBLEM: WHAT ARE THE FOES FROM WHICH WE MUST PROTECT USEFUL PLANTS?

Why must useful plants be protected? When you stand in a beautiful garden, it is hard to realize that dangers surround plants. You are more or less familiar with the dangers that beset the lives of animals—the enemies which attack and the diseases which may kill. But do you know that plants, too, are in constant danger of attack? Storms, fires, and floods injure and destroy plant life. Insects kill millions of plants each year. Plants may become diseased and die because certain other plants live upon them, absorbing food from the plants upon which they live.

Fungi—plants without green cells. You are probably familiar with the toadstool and the mushroom. These plants do not contain green coloring matter, that is, chlorophyll, and consequently they cannot manufacture starch from water and carbon dioxide in the presence of sunlight. They are members of the large plant group called *fungi.* Many of the fungi depend upon decaying animal or vegetable matter for food; but some of them live on the juices of living plants. A plant or an animal that lives and feeds on the living body of another plant or animal is called a *parasite.* One that lives on dead and decaying matter is called a *saprophyte.*

Mushrooms and toadstools, the largest of the fungi. How many of you have ever seen a toadstool or a mushroom growing? These fungi grow on old decaying logs and even in very rich soil in which there is enough decaying vegetable matter to supply them with food. They reproduce their kind by the formation of spores which are scattered by the wind. Sometimes the spores are scattered so that the mushrooms or toadstools grow in a ring. It was once a popular superstition that these "fairy rings" served as stools for fairies and elves.

Some mushrooms are edible, but many are not because they are poisonous. No general rule can be given by which edible mushrooms may be told from those that are poisonous. Only a person who can tell with certainty whether a mushroom is edible should gather them. Of course it is safe to purchase mushrooms from reputable dealers.

Certain of these fungi such as the "bracket" toadstool grow on living trees. What do such growths tell about the condition of the tree?

Bacteria, rusts, mildews, and molds. Other fungi are called *bacteria*, some of which, as you have learned, cause diseases in man; others, called *rusts and smuts*, attack growing grains as well as other grasses and so do great damage to crops; a third, *mildews* (Fig. 330), cause rot in potatoes, root crops, and grapes; and a fourth, *molds*, form on bread, meat, canned fruits, and other foodstuffs and even grow on wood and paper.

There are many kinds of fungi which attack useful plants. The chestnut canker, for example, is a fungus that has killed a large number of chestnut trees in the United States. The blister rust is doing great damage to pine trees. For years wheat rust has caused an annual loss of about $50,000,000 to farmers in the United States.

Experiment 154. To grow mold. Expose a piece of moist bread to air. Place it under a glass jar and keep the jar in a warm place. Examine the bread from day to day with a magnifying glass and note what has taken place. Is anything growing on the bread? If so, what was its only possible source? A frequent growth found is the common bread mold.

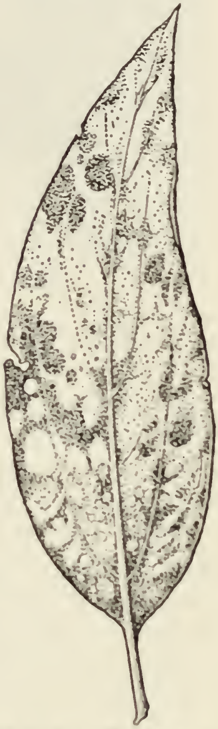
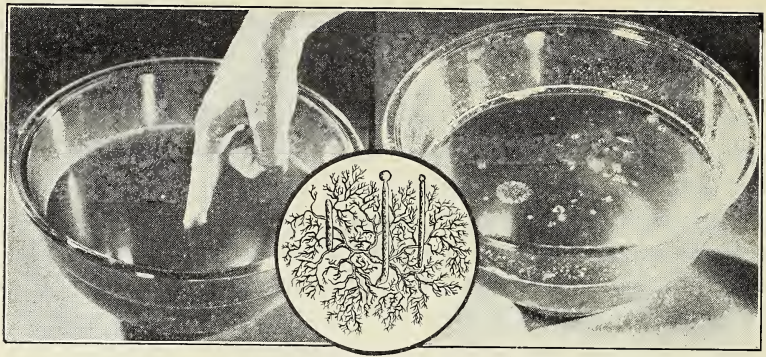


FIG. 330. Under surface of a willow leaf attacked by mildew, caused by a parasitic fungus.

In general the growth of bread mold is typical of the growth of fungi. Bread mold grows from spores. If the spores happen to light on food or other organic matter in a moist and warm place, each spore begins to send out tiny threads (hyphae). Some of these threads penetrate the bread and absorb nourishment from it. Before long, small black bodies appear on the ends of the hyphae which stick out from the bread. These are full of spores, each of which is capable of producing a new



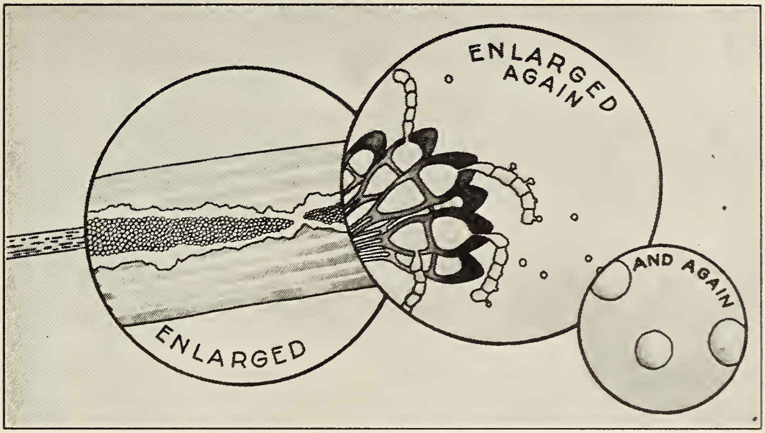
Courtesy Frigidaire Corporation

FIG. 331. At the left is a bowl of recently prepared gelatin. At the right is the same gelatin, two days later. Note the growth of mold. At the center is a diagram of highly magnified mold.

mold plant if it falls upon material and under conditions favorable for growth.

A fungus plant which grows on a living plant absorbs its nourishment from the sap of the plant. If conditions are favorable, these fungi may grow and spread so rapidly that the plant on which they are living is killed.

Wheat rust, a fungus that raises the price of bread. Among plant diseases, *wheat rust* has for many years been one of the most dreaded because it destroys a plant on which so large a part of the civilized world depends so much for food. The rust or fungus appears on the wheat leaves and stalks as reddish-brown spots (Fig. 332). It extracts its food from the stalk and leaves of the wheat plant. As a result very little if any grain is produced on a stalk affected by rust. The life-history of rust is most interesting because it lives part of its life on the American barberry bush. The spores produced on the wheat plants during the summer are red in color; these spores spread the disease from wheat plant to wheat plant, or from wheat to grass and back to the wheat again. In autumn, winter spores are formed on the wheat, straw, or grass and remain on them until spring. These spores, however, cannot grow on wheat plants. In the spring they produce colorless bodies called sporidia. These are blown about by the



Courtesy Bureau of Plant Industry, U. S. Dept. of Agriculture

FIG. 332. In winter the spores of rust on grains are black and when magnified appear as you see them in this illustration.

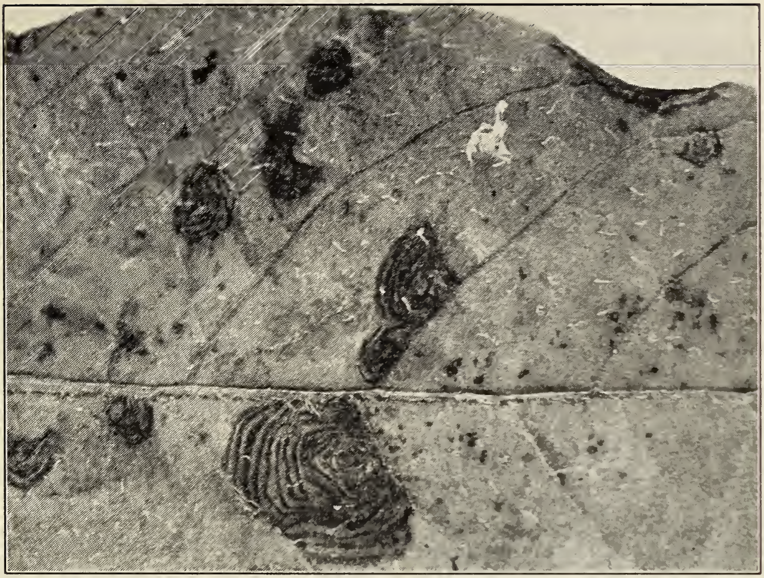
wind, but cannot grow unless they land on the barberry, where they produce a disease that resembles wheat rust so little that for many years no one realized that it was the same as wheat rust. The spores produced on barberry bushes start the rust infection of wheat plants all over again. The remedy for wheat rust, therefore, is to destroy the American barberry. Rotation of crops, that is, planting other crops than wheat until the rust spores have died out, aids in controlling the disease. One of the crop rotations suggested is wheat one year, grass the second, corn the third, and wheat again in the fourth year.

Brown rot, a fungus that attacks fruits that have stones. A common fungus plant, *brown rot,* attacks such fruits as plums and peaches. The fungi appear as brown spots on the fruit. Fruit thus diseased either rots and falls to the ground or shrivels and clings to the tree, thus providing a place for the spores to live throughout the winter. In the spring these spores develop and are carried by the wind to blossoms of fruit trees, where they begin their work again. Brown rot may be partially controlled by burning any fruit affected by it as soon as the disease is discovered and by spraying the fruit trees with Bordeaux mixture (a mixture of copper sulfate, quick lime, and water) and later with lime sulfur.

Pear blight, tiny enemies of the pear tree. *Pear blight* attacks pear trees, apple trees, and occasionally plum trees. It is a plant disease that is caused not by fungi but by bacteria which are one-celled plants. The first symptom of the disease is the sudden death of the tips of growing twigs or of blossoms. The leaves turn yellow and later dark brown, and the tree seems to be dying from the top down. The diseased limbs should be removed and burned as soon as these symptoms appear, but something more is usually necessary to blot out this disease. The bacteria move down the tree and form cankers on the large limbs and the body of the tree. Here they pass the winter. In the spring, sticky, milky drops containing large numbers of the bacteria of the blight, ooze out of the cankers and insects carry bacteria to the flowers and other parts of trees. The logical points of attack, then, are the cankers. These should be removed with a sharp knife, the wounds scraped clean and washed with a weak solution of corrosive sublimate, one part to five hundred of water. In a day or two the wounds should be painted with lead and oil.

Although this is the only bacterial disease of plants which we shall discuss, there are many others, among them black rot of cabbage and soft rot of turnips.

Mildews, robbers in the vegetable patch. The mildews are a group of fungi very destructive to fruits and vegetables such as potatoes, lima beans, onions, citrus fruits, and grapes. Probably the most destructive mildew is that called *late blight,* which attacks the potato plant. Mildew spores are always present in air in summer, and if they land on a potato leaf under proper conditions of temperature and moisture they soon send out slender tubes which enter nearby breathing pores (stomata) of the leaf (Fig. 333). Once inside the leaf the tubes grow rapidly and send out numerous branches which absorb the contents of the cells of the leaf; these tubes even grow down through the stalk to the tubers. On whatever plant they grow, they kill its cells so quickly that the term "blight" is quite applicable. These fungi commonly pass the winter in diseased potatoes.

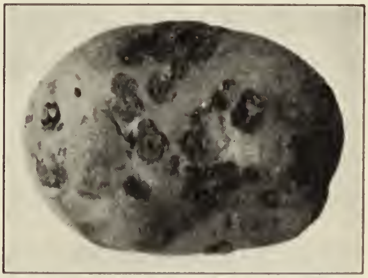


Courtesy Bureau of Plant Industry, U. S. Dept. of Agriculture

Fig. 333. Advanced stage of blight on a potato leaf. Since this disease attacks the under-side of a leaf, how can it be controlled?

Consequently great care must be taken to secure seed potatoes free from mildew spores. Late blight of potato plants may be partially controlled by spraying the plants with Bordeaux mixture.

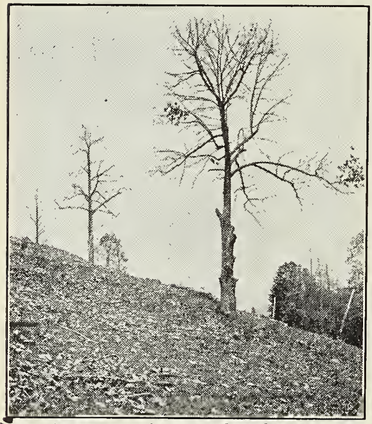
Potato scab, a dangerous enemy of the potato. The fungus disease known as *potato scab* may do much damage (Fig. 334). These fungi can live in the soil over the winter, hence the only remedy is the rotation of crops. To prevent any possibility of planting seed potatoes infected with scab, seed potatoes should be soaked in a solution of formaldehyde, one pound to thirty gallons of water, long enough to kill the fungi.



Courtesy Ohio Agricultural Experiment Station

Fig. 334. What can be done to control this disease, potato scab?

Chestnut canker, the killer of chestnut trees. Probably the fungus known as *chestnut canker* was brought into the United States from Japan (Fig. 335). As the chestnut canker fungi develop, millions of spores are produced, which are blown about by the wind. After spores land on the bark of a tree, they send little hairs into the cambium layer. These hairs absorb food on its way to the living cells of the tree. In a short time the tree dies from starvation. The only remedy seems to be to cut down and burn infected trees.



Courtesy Ohio Agricultural Experiment Station

FIG. 335. Chestnut blight, caused by a fungus, was probably brought to this country from Japan, thus showing the need for rigid inspection of imported plants. Most of the chestnut trees throughout the country have been killed by this blight.

Smut, a suffocating black powder. Many of us are familiar with the loose black or dark brown powder found on the heads of oats and wheat or on the ears and stalks of corn. This powder is made up of millions of minute spores of fungi known as *smut.* When wheat or oats affected by smut is threshed, spores are often attached to any chaff that is not completely removed from the grain. If this grain is used for seed, spores germinate and force their way into the stalk of the young plants. When the plant begins to "head" the smut fungi develop a mass of small threads within the tiny blossoms. These threads produce countless black spores that make up the powder known as smut. Spores of smut may be killed by soaking the grain that is to be used for seed in a dilute solution of formaldehyde. Corn and onion smut are quite common, especially if these plants are grown year after year on the same ground.

Black knot, living knots on the cherry tree. This fungus disease affects plum as well as cherry trees. It causes the growth of black knots on the branches and trunks of the trees. In warm weather the millions of spores that are produced in these knots are carried by the wind to other cherry and plum trees. All diseased branches and badly infected trees should be cut and burned. Spraying diseased parts with Bordeaux mixture will help to prevent the spread of the disease.

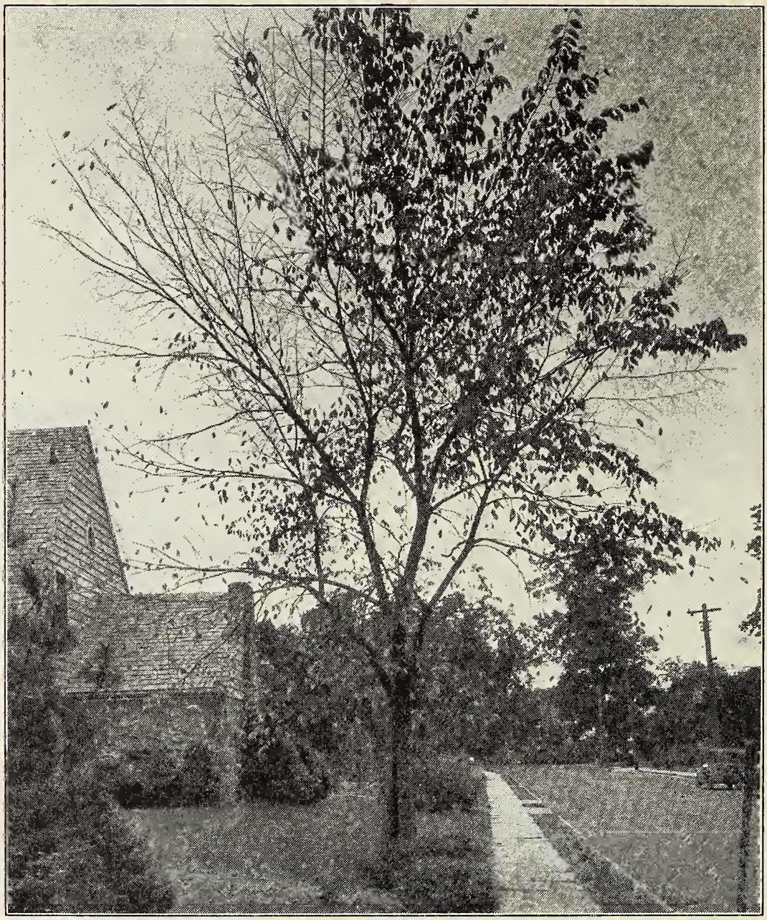
Peach leaf curl, a robber in the food factory. This disease is due to the growth of a parasitic fungus which enters the leaf, causeing it to become enlarged and curl. The diseased leaves fall early in summer. Winter spraying with Bordeaux mixture or with lime sulfur will destroy the spores of this fungus.

Dutch elm disease, a new enemy in our country. This disease is caused by a very destructive fungus. First discovered in the Netherlands in 1919, it has since been found in other parts of Europe and in several places in the eastern part of the United States. This disease works very rapidly, killing an elm tree in one or two years (Fig. 336).

If there are any elm trees on your property, watch for wilting or yellow leaves. If you find any, break off a twig and examine it to see whether brown streaks show in the young wood. If they do, cut infected branches about the size of a lead pencil and send them to the agricultural experiment station nearest your home. The scientists there will advise you what to do.

Yeast, the plant that causes dough to rise. Yeast plants are one-celled fungi, too small to be seen by the naked eye. Since yeast lives on non-living vegetable matter, it is a saprophyte. What is the difference between a saprophyte and a parasite? Yeast plants growing in weak sugar solutions split up the sugar into alcohol and carbon dioxide. When yeast is put into dough (a mixture of flour, water, and sugar), it splits up the weak sugar solution in the dough, setting free bubbles of carbon dioxide. These bubbles make the dough "rise" as they expand. The heat of the oven in which the bread is baked kills the yeast plants and thus stops their action.

If fruit juices or fruits are exposed to air, they will ferment. The fermentation of fruit juices is caused by yeast plants, present in the air, finding their way into the juices. These yeast plants act upon the sugar to form alcohol and carbon dioxide.



Courtesy Bureau of Plant Disease, U. S. Dept. of Agriculture

FIG. 336. Even in fine residential sections where plants are carefully tended, the Dutch elm disease has made inroads.

One yeast cake contains millions of yeast plants. When placed in sweetened water these plants increase in numbers very rapidly. They do not reproduce by cell division, as most one-celled plants do, but by *budding* (Fig. 337). When a yeast plant buds, as in cells *A* and *B*, part of the parent cell forms one or more new cells, such as *C*, which eventually separate from the parent cell.

Most yeast plants also produce spores, sometimes as many as four from a single plant. If conditions are favorable, these spores will develop into new yeast plants.

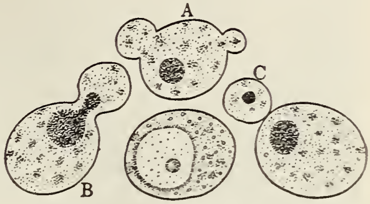
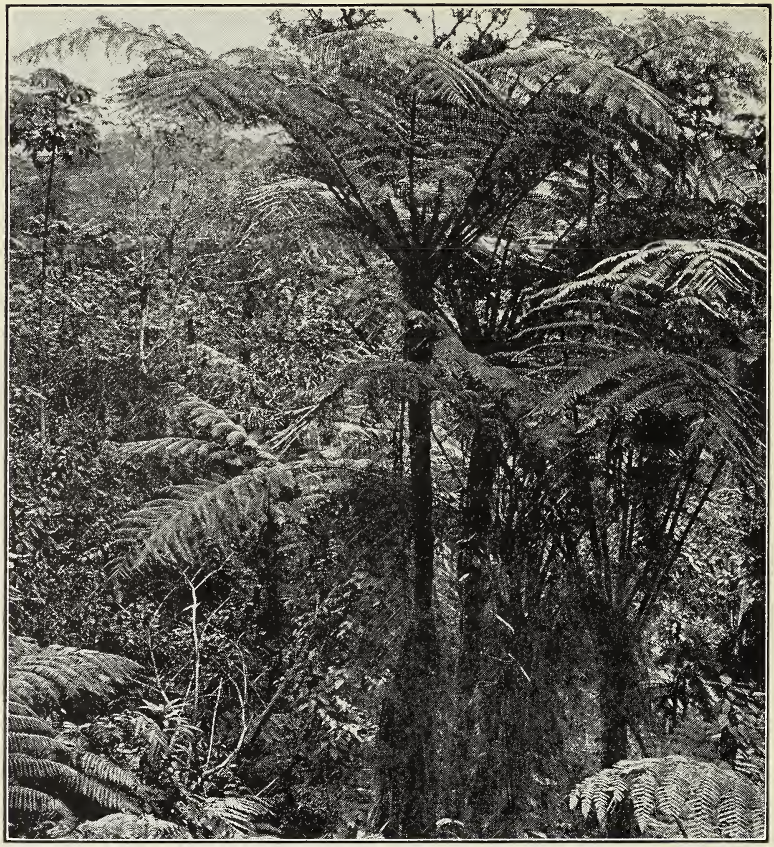


FIG. 337. Yeast plants growing by budding.

Mosses, the green carpet of the forest. Mosses and ferns are plants of higher development than algae and fungi. As they contain chlorophyll bodies, they are also able to manufacture their own food. Explain. Mosses as a rule are shade-loving and moisture-loving. They are frequently found in forests, spreading a beautiful green carpet under the trees. Their need of moisture is evident from their tendency to grow in swamps and along the wooded shores of lakes. However, not all soft, green, moss-like plants are moss. Investigation of the so-called mosses on watering troughs or water buckets shows that many of them are algae. A few mosses must be submerged in water to remain alive; many of them grow out of water; and a few can even endure being dried until they crumble and yet revive when moisture is supplied them. This behavior of certain mosses is very unusual, for drying destroys the protoplasm of most living things.

Ferns, feather-like plants. Ferns are slightly higher developed plants than mosses. As true ferns grow best in damp, shady places, they flourish in densely-wooded regions in the tropics, and also in towns, where they grow to immense sizes (Fig. 338). The little brown dots on the under surface of the leaf are the spore cases of ferns. From these spores, new ferns develop.

Weeds, undesirable plants. A very effective enemy of cultivated plants is the *weed*. Weeds are plants growing where they are not wanted. In a garden all plants that are not cultivated as flowers or vegetables are weeds. On a tennis court all plants are weeds. Most kinds of common weeds are hardy. They possess very effective ways of scattering their seed; and they can grow under conditions highly unfavorable to the growth of cultivated plants. The attempts of man to destroy them must be carried on persistently if any headway is to be made. Weeds flourish in



Courtesy Mr. William R. Maxon.

FIG. 338. Even ferns as large as trees develop from spores.

poor soil and in fertile soil; they crowd out other plants by absorbing sunlight and soil food so that the other plants die of starvation. Certain weeds are so persistent in their growth and spread so rapidly that the United States Department of Agriculture classes them as national pests and recommends measures which it is hoped will lead in time to their extermination.

Weeds have some real value, however. They help to make soil and to renew soil in worn-out regions. When soil, on account of unscientific farming, becomes too poor to grow crops, weeds will still grow on it and help build up the soil. Can you tell how? As weeds spring up quickly and grow rapidly in soil in which vegetables are growing, it is necessary for farmers and gardeners to cultivate the soil frequently to keep them down. As a result of this cultivation the vegetables are helped to grow.

Forest fires. Wholesale destruction of beautiful and valuable trees has been caused by forest fires. To prevent the destruction of such valuable property, millions of dollars are being spent by the national government and state governments to purchase huge tracts of timber for forest preserves. We, as individuals, can help to prevent such fires by taking proper care of a fire built in or near a forest. A fire should never be left until the last spark is extinguished. If water is not available, dirt should be scraped over the spot where the fire stood. If these precautions are taken, sparks will not be scattered later by a breeze into dry grass or leaves. Smokers especially should be extremely careful in any forest; careless smokers, by dropping burning matches, cigarettes, or cigars, have started many devastating forest fires. In a forest in which the underbrush is cleared out there is not so much danger of forest fires. Wide strips of cleared ground extending through a forest provide one of the most effective aids in controlling forest fires. Moreover, these strips give fire fighters an opportunity to check the progress of a fire if one gets started. What other ways can you name by which dangerous forest fires are prevented, located, or controlled?

Animal pests. In addition to the parasitic enemies of plant life many kinds of animal pests destroy millions of dollars' worth of crops each year. Among these are the Gypsy moth, army worm, Japanese beetle, grasshopper, San José scale, corn borer, potato beetle, codling moth, boll weevil, and the Mediterranean fruit fly. The control and extermination of each kind of pest depends upon a knowledge of (1) its life history; (2) its food; (3) its enemies; and (4) what poisons can be used for killing it.

Grasshoppers do a great deal of damage but so far effective ways to control them have not been discovered. Certain of their natural enemies, such as the robber fly, digger wasps, and spiders, kill many of them. Turkeys devour them in great numbers.

Lime sulfur sprayed on fruit trees when in blossom and again later on will help to control the codling moth. Rotation of crops helps to deprive the corn borer of its food supply, the corn plant. The most effective way to destroy the cotton boll weevil seems to be to gather and burn all affected cotton plants late in summer, after which the ground should be plowed to expose the places in which the insect may be hidden. Paris green sprayed on the potato plants poisons the potato beetle, which eats the leaves of the plant. Plant lice may be exterminated by spraying the plants with an oil emulsion. The best treatment for San José scale is lime sulfur spray.

The Hessian fly is a pest very destructive to winter wheat. It lays its eggs on the leaves of the wheat plant in autumn. The next summer the young insects find their way into the joints of the plant and absorb food needed by the wheat plant itself. It is difficult to combat the Hessian fly. One successful method is the "trap" crop. Narrow strips of wheat are planted early to attract the flies. After they lay their eggs these strips are plowed under. The main wheat crop planted later escapes the ravages of the fly. The yearly damage to our wheat crop has been estimated as high as 20,000,000 dollars. This insect is supposed to have been brought to the United States in straw bedding used for Hessian soldiers during the Revolutionary War.

The Gypsy moth, which has done great damage, especially in New England, by eating the leaves of trees, may be controlled by (1) spraying the trees with a solution of arsenate of lead, (2) by importing their natural enemies, especially the Calosoma beetle, from Europe, and setting them free in infested districts, (3) treating with creosote, egg masses found on trees and even on fence rails.

The cotton boll weevil, whose first home is thought to have been in the tablelands of Central America or Mexico, first entered the United States about 1890. The adult boll weevil is about one-fourth of an inch long, with a breadth one-third of its length.

The most recent and most destructive insect invader of the United States is the Mediterranean fruit fly. The United States Government in 1929 appropriated 4,250,000 dollars to destroy this pest if possible. It attacks vegetables as well as fruit.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

alga
blight
Bordeaux mixture
canker
fungus
formaldehyde
Gypsy moth
Hessian fly
hibernate
mildew
mold
hyphae
parasite
saprophyte
spirogyra
smut
rust
yeast

Write the number of each item on your paper and after it the word that completes the statement.

1. Single celled plants reproduce by ________.

2. Other flowerless plants are reproduced by ________.

3. Plants that grow on other living plants are called ________.

4. A common plant found in green scum on stagnant water is ________.

5. A plant that feeds on dead matter is called a ________.

6. The germinating spores of mold plants send out ________.

7. The greatest number of animal pests belong to the class of animals known as ________.

Which item in each of the following lists does not belong with the others?

8. scum; alga; spirogyra; spore.

9. carbon dioxide; saprophyte; yeast; alcohol.

10. wheat rust; fungus; American barberry; disease; bread mold.

Which of these statements are true? If any are false, re-state them in correct form.

11. All plants produce flowers.

12. An alga is a parasite.

13. Fungi make their own food.

14. Certain kinds of fungi are used for food.

15. Molds grow from seeds.

16. Chestnut trees are being killed by smut.

17. Usually the "spoiling" of canned fruit is due to the growth of yeast plants.

18. The growth of the American barberry should be encouraged.

THOUGHT EXERCISES FOR UNIT XIII

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Plants that contain chlorophyll make and store up food.

Questions or Problems

1. How do the terms cell, tissue, organ, and organism differ in meaning?
2. Why are leaves sometimes referred to as factories?
3. Of what advantage are bright colors to a plant?
4. Would a single stalk of corn in a field be likely to produce a well developed ear? Discuss your answer.
5. Why does a plant have a stem?
6. Trees in a dense forest have few limbs near the ground. Why?
7. A tree was known to bear two kinds of apples and one kind of pear at the same time. How was this possible?
8. How does the production of fruit help certain plants?
9. Give three reasons why lumber has increased rapidly in price during the last twenty years.
10. Why do useful plants need protection?
11. Why are mushrooms pale in color?
12. How do algae contribute to the health of mankind?
13. Why is a fern considered a higher type of plant than a fungus?
14. How can people help to prevent forest fires?

Projects and Reports

1. Make a survey of the wild plants which grow in your community. With the aid of pictures and sketches of your own, describe the leaves and flowers of five of these plants. Use such terms as veining, sepals, petals, stamens, and pistils.
2. Study the life and work of Luther Burbank or John Burroughs. Report to class.
3. Make a hotbed or cold-frame and report to class how it was constructed, also, report results of your planting. Compare the temperature inside with that on the outside.

4. Take a census of your neighborhood trees and report the number of each kind. Estimate the probable age of several trees. Of what particular value to man is each kind of tree?

5. Make a study of the uses to which men put the bark of trees. List these uses and report to class how the bark is prepared for use in each case.

6. Collect as many blocks of wood as you can and study the grain. Read in the library the cause of the formation of grain. Label the blocks as to name: pine, oak, etc. Explain to the class how these can be identified.

7. Make a study of tree surgery. Read on this subject and write for circulars to companies that engage in this kind of work. Report to class: methods used, benefits to trees, dangers of exposed bruises, etc.

8. Write to your state university or agricultural station, also to the U. S. Department of Agriculture, for bulletins and sketches of one of the following: wheat rust, pear blight, mildews, Hessian fly, Japanese beetle, San José scale, corn borer, or any other plant enemies that may arouse your interest. Report to class, show pictures of their appearance in different stages, discuss their destruction of plants and the remedies for destroying them.

References for Reading and Study

1. Barron, Leonard, Editor, *The Complete Book of Gardening*. Doubleday, Doran & Company.

2. Chamberlain, C. J., *Elements of Plant Science*, Part I. McGraw-Hill Co., Inc.

3. Darrow, F. L., *St. Nicholas Book of Science*, Chapter IX, Rubber. D. Appleton-Century Company.

4. Darrow, F. L., *Thinkers and Doers*, Chapter XIII, Story of Rubber. Silver Burdett Company.

5. DuPay, Wm. A., *Wonders of the Plant World*. D. C. Heath and Company.

6. Gruenberg, Benj., *Elementary Biology*, Parts II, III, and IV. Ginn and Company.

7. Harwood, W. S., *New Creations in Plant Life*. The Macmillan Co.

8. Kenly, Julia, *Green Magi*. D. Appleton-Century Company.

9. Mathews, *Field Book of American Trees and Shrubs*. G. P. Putnam's Sons.

10. Mathews, *Field Book of American Wild Flowers*. G. P. Putnam's Sons.

11. Meier, W. H. D., *School and Home Gardens.* Ginn & Company.
12. Pack and Gill, *Forest Facts for Schools.* The Macmillan Company.
13. Parker and Cowles, *The Book of Plants,* Chapter IX, Yeasts; X, Molds; XIX, Forest Fires; XIII, Weeds. Houghton Mifflin Company.
14. Rogers, Julia, *The Book of Useful Plants.* Doubleday, Doran & Company, Inc.
15. Sadtler, Samuel S., *Chemistry of Familiar Things* (paper). J. B. Lippincott Company.
16. Surface, G. F., *The Story of Sugar.* D. Appleton-Century Company.
17. Transeau, E. N., *Science of Plant Life.* World Book Company.
18. Wisehart, M. K., *Marvels of Science,* Chapter XIII. D. Appleton-Century Company.

UNIT XIV

OF WHAT USE ARE ANIMALS TO MAN?

Exploring the Animal World

Scientists have made many interesting discoveries about animals that lived in the past. Great awkward-looking dinosaurs which shuffled through swamps of thick vegetation and muck in ancient times would look strange and terrifying to us today. Some of these a hundred feet in length, with long necks, small heads, and long tails lived on plants. Other huge animals with large heads, strong jaws, and large strong teeth lived on the flesh of other animals. Changes in the earth's crust and in climate made it impossible for these huge monsters to survive. Perhaps you have seen the skeletons of certain of these animals in museums.

When man came upon the earth probably most of these animals had disappeared. But other animals just as menacing to man had come to take their places. Man's progress in civilization is a long record of his struggle to protect himself from certain wild animals and to domesticate others. Some of these domesticated animals he uses as beasts of burden and still others supply him with materials which he uses for food, shelter, and clothing. While man is now able to protect himself from most dangerous wild animals, there are others that threaten to destroy his food supply and other plants and animals that are necessary for his comfort and happiness.

Although animal life has changed greatly since animals first came upon the earth, there are existing today many curious animals, especially among the lower forms, that will arouse your curiosity. Certain kinds of these have no mouth, no eyes, no limbs, no heart; in fact, certain kinds do not have a definite shape. We will trace the increase in complexity of animal life from the simplest up to those we commonly see in the zoo or those on the ranch and in the meadow which furnish us with food and many other products in our daily life.

CHAPTER XXIX

WHAT ARE THE KINDS OF ANIMALS AND HOW ARE THEY USEFUL TO MAN?

Do you know:

How some tiny animals paralyze their prey? That the earthworm comes out at night for its food? What man's keenest competitor for the food supply of the world is? That a female bee or ant is made a queen by feeding her specially prepared food? That the body of a fish is heavier than water? How many chambers there are in the heart of a frog? That reptiles and birds resemble each other rather closely? That lions, bears, cats, cows, and dogs belong to the same great class of animals called mammals? That natural silk is an animal product?

PROBLEM: HOW ARE ANIMALS LIKE PLANTS?

How do animals differ from plants? You have learned in your study of plants that all living matter has distinct processes which distinguish it from non-living matter. Name these seven life processes. If you cannot recall all of them, turn to page 508 and refresh your memory.

In addition to the life processes which are common to all animal and plant life, animals show much evidence of feeling and activity. They move from place to place under their own power, while most familiar plants are anchored to the soil and are moved only by the action of sunlight, wind, water, and other external forces. Animals, such as the dog and the horse, are capable of showing affection for their masters and display evidences of pleasure and pain; they actually become companions to man.

How do we classify animals? Just as plants are classified by their structure and methods of growth and reproduction, so are animals classified by the development and complexity of their organs. A worm is simpler in structure than a bird; hence we say that the worm is not as high in the animal scale as a bird.

The structure of a dog is very complex; a dog can be trained to drive cattle on the farm, to herd sheep, to act as "watchman" in a building or in an automobile, and to perform many stunts which interest and delight us. This complexity of structure and the ability to learn gives the dog a higher place in the animal scale than most other animals.

You know that human beings are better equipped for life than any other animals because of their ability to *think* and to change their surroundings if they are not favorable. This places man at the top of the animal scale.

In this unit we shall study first the lowest forms of animal life, then higher forms, and finally man. As we study each animal we shall learn how it performs each of the seven fundamental processes of all living matter.

PROBLEM: WHAT ARE THE CHARACTERISTICS OF ONE-CELLED ANIMALS?

Protozoa, one-celled animals. The simplest and smallest of all animals, the *protozoa*, consist of just one cell. They are found in water everywhere; every fresh-water lake is the home of millions of protozoa and the sea likewise contains them in countless numbers. Certain protozoa live in other animals and plants. Most of these are harmless, but some of them are the germs which cause diseases, such as, malaria, typhus, and African sleeping sickness.

Protozoa are so small that a microscope must be used to see them. In spite of their small size, they are of use to man because they are one source of food for clams, oysters, crabs, shrimps, fishes, and the like.

Some kinds of protozoa are covered with a hard protective shell composed of lime or other mineral matter. These shells, deposited at the bottoms of ponds or oceans when the animals die, form the basis of limestone and chalk. The chalk cliffs of Dover in southern England were formed from such deposits. These cliffs extend two or three hundred feet above the sea, and on a clear day they can be seen from the opposite shore of the

English channel. Some of the pyramids in Egypt were built of limestone formed from the deposits of protozoa.

The amoeba—a one-celled animal without fixed form. The *amoeba* is the simplest known form of animal life. It is one kind of protozoa. It consists of a single cell which changes its shape as it moves through the water. Sometimes the amoeba contracts into a ball; at other times it lengthens and becomes flat; sometimes it is almost star-shaped; and again it may shorten itself and become blunt. The amoeba is a colorless, almost transparent bit of protoplasm. It secures its own food, takes in oxygen and gives off carbon dioxide, grows, and reproduces its kind. Though a single cell the amoeba performs all the functions of life.

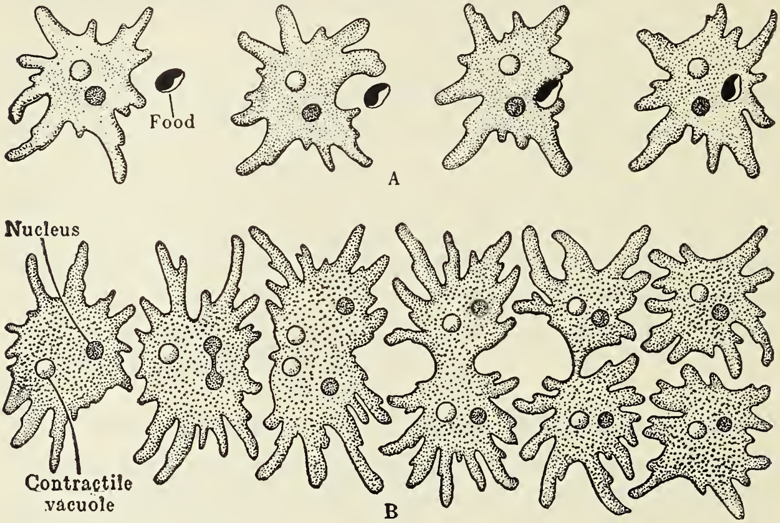


Fig. 339. Explain from A how an amoeba takes in food and from B how it reproduces itself.

The amoeba is found in the slime and sediment of stagnant water. It moves by pushing part of its cell in one direction and then contracting the rest of the cell toward the part pushed out. The amoeba has no mouth or stomach; but if any part of its body comes in contact with a bit of food, the amoeba surrounds it as shown in Figure 339A. Some of the food is changed into protoplasm and becomes part of the cell; the rest is ejected from the cell as waste matter. The amoeba uses the oxygen dissolved in the water in which it lives to provide energy for its life processes. Although it has no lungs or any other breathing organs, it takes oxygen into its single cell through every part of the outer covering of the cell and gives out carbon dioxide. By what means does this process of breathing take place?

This tiny animal reacts to certain stimuli such as light, food, moisture, and sudden jars. If an amoeba comes in contact with a grain of sand, it moves away from it. The amoeba can be made to start and stop its movements by physical or chemical changes.

In addition to the functions already described, the amoeba grows and reproduces its kind. When the amoeba has become fully developed, it divides to form two new cells each of which is like the parent cell except that it is smaller. The cell of the amoeba divides in a manner similar to the method of a plant cell (Fig. 339B). If conditions are favorable, each amoeba thus formed will in turn grow and divide as did the parent amoeba.

Summarize briefly the way in which an amoeba moves, takes in food, gives off waste materials, breathes, is sensitive, grows, and reproduces itself.

The paramecium—a slightly higher type of one-celled animal. Another of the protozoa is the *paramecium.* The paramecium is slightly more complex than the amoeba and is much larger, being nearly one-fourth of a millimeter in length. Although this is larger than the amoeba, you should remember that protozoa are very tiny animals that must be studied with the aid of a microscope.

Experiment 155. To observe the structure and movement of a paramecium. (The teacher should prepare a hay infusion by placing a little hay in some water and letting the mixture stand for several days.) Place a drop of water from the hay infusion under a microscope and look at it closely. Are there any small rapidly-moving bodies in it? Do you see any that look like the tiny animal in Figure 340. Try to get a good view of one of the tiny animals with the high power lens of the microscope. Do they move forward with the same end always first? Do they collect in any place? If so, can you suggest a reason why they should do so?

The tiny animal which you have just observed is a paramecium. Figure 340 shows the structure of the paramecium. Notice that the paramecium is a slipper-shaped cell bounded by a thin membrane. Find the funnel-shaped cavity which serves the purpose of a mouth. Projecting through the membrane which envelops the cell are many delicate threads of protoplasm called *cilia.* Locate these on the diagram. The cilia move in the water like tiny oars, thus assisting the paramecium to move about in its search for food.

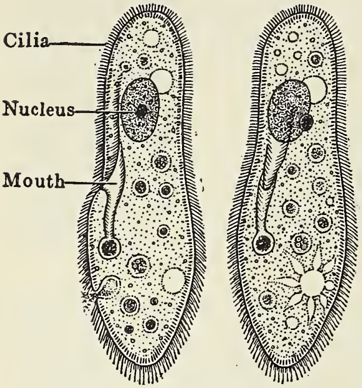


FIG. 340. In what ways is a paramecium more highly developed than an amoeba?

The development of a part of the body of an animal for doing special work, as the development of the cilia in the paramecium, is called *specialization.* The extent to which parts of an animal are specialized helps to determine whether it is high or low in the animal scale. Why do the cilia of the paramecium make it a higher form of animal than the amoeba?

The paramecium reproduces by cell division, but in a slightly different way than the amoeba. The new amoeba, as you know, is like the cell from which it was formed except that it is smaller; its development consists only in growing larger. The young paramecium, however, may have no mouth when it first separates from the parent cell. Its development, then, consists not only in growing larger but also in developing a mouth.

The paramecium, like the amoeba, responds to stimuli and will move away if touched or disturbed in any way.

Summarize briefly the life processes of the paramecium.

Other protozoa. Although it is impossible to discuss in this book other forms of protozoa, you may be interested in reading about other kinds of these microscopic animals. You can learn many valuable and interesting things about their structure and ways of living from any biology text.

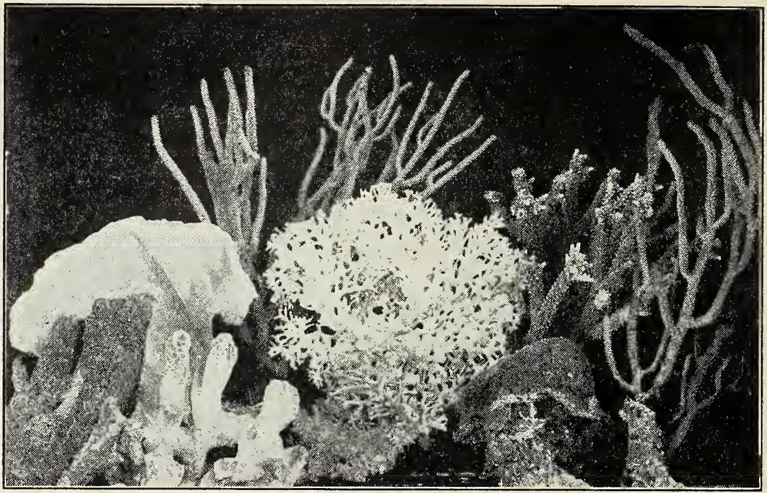
PROBLEM: WHAT ARE THE CHARACTERISTICS OF SOME OF THE SIMPLER ANIMALS?

Sponges—skeletons that are used to wash blackboards. Did you know that the *sponge* used to wash the blackboard is the skeleton of an animal? Sponges are largely salt-water animals, although a few kinds grow in fresh water. A sponge is a mass of animal cells which work together as a single unit. These cells do not move about, but stay in one place, taking in food from the water through pores in the side walls, and continually casting off waste material.

Sponges grow in great numbers on the reefs off the coast of Florida. The fishermen go out in large boats for weeks at a time. From these large boats the men go in power boats and when they come to the place where the sponges grow, they dive for them. The sponges are spread out on the deck or on the sand along the shore until the fleshy part of the animal decomposes. They are then placed in water and beaten from time to time to dislodge the decayed material. In shallow water the fisherman uses a long spear. When they are thoroughly clean, they are hung up to dry, after which they are ready for the market.

Coral—skeletons that are used as jewelry. Coral is made up of skeletons of animals called *corals* (Fig. 341) which live in the warmer sections of the sea. They grow mostly on reefs where the breaking waves supply them with oxygen. The hard skeleton remains long after the corals are dead and often such great piles of skeletons are formed that whole islands are made. The southern tip of Florida and many of the South Sea islands had their origin in living corals.

In the group of animals to which corals belong are other animals which some of you may know. If you live near the ocean you are probably familiar with jelly fish. Sea anemone (Fig. 342) and hydra also belong to this group. All of these animals are simple in structure. They are bags of living material, each of which has a central cavity through which food materials and waste materials are carried in and out of the animal by water. We shall consider one of this group in more detail—the hydra.



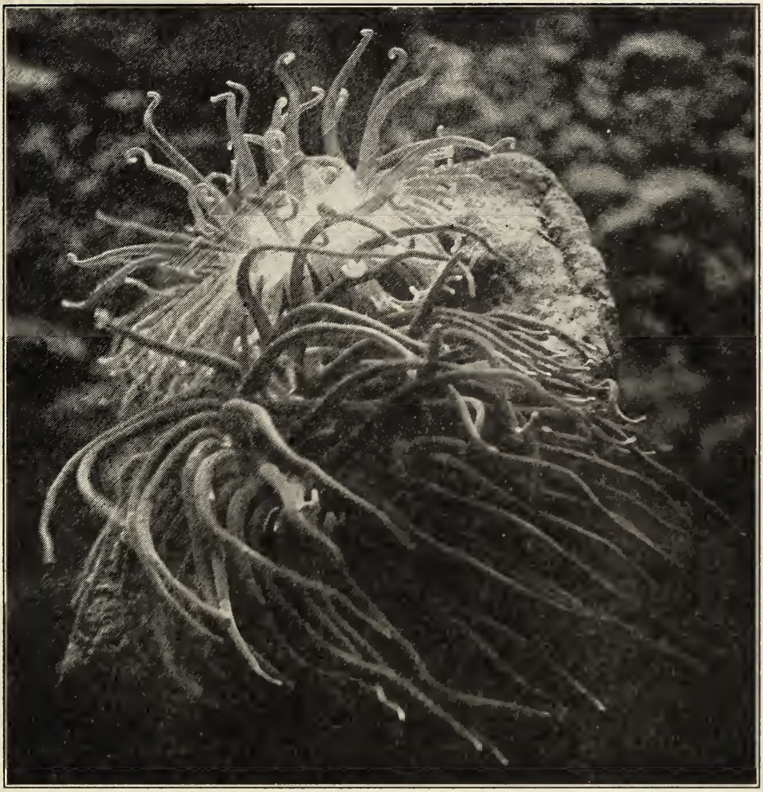
Courtesy William Beebe

FIG. 341. Coral beds may well be called the gardens of the sea, for coral grows in fanciful shapes in white, yellow, pink, red, or orange.

The *hydra*, to the unaided eye, appears like a tiny white or greenish, jelly-like particle. This animal is not carried about by every movement of the water in which it lives because it is able to attach itself to a submerged stone, piece of wood, or water plant by means of a sticky secretion from cells at its base. It does not have to stay in one place all its life, however, for it can loosen itself and move.

The body of the hydra is shaped like a tube (Fig. 343). The wall of the tube is composed of an outer and an inner layer of cells. Some of the cells of the outer layer are very irregular in shape and possess especially large nuclei. As these cells are more sensitive to stimuli than the others, they may be considered *nerve cells.*

At one end of the tube is the mouth of the hydra. Around this are from six to eight hollow, arm-like organs called tentacles, which are outward projections of the body walls. Inside many of the cells of the wall of the hydra and especially inside the cells of the tentacles are small oval sacs in each of which is folded or



Courtesy William Beebe

FIG. 342. The varying colors and the waving tentacles of a sea anemone remind one of a beautiful flower. These strange sea animals usually spend their entire life attached to a rock. Can you tell from the illustration how they secure food from the water around them?

coiled a fine, long threadlike growth. When the tentacles touch an enemy of the hydra or one of the free-swimming organisms used for food, these threads shoot out from their sacs, stinging and poisoning the prey until it is paralyzed. The tentacles then contract suddenly and bend inward, bringing the captured organism to the hydra's mouth. The food enters the tube, i.e., the body cavity of the hydra. Here it is digested by juices secreted by the cells of the inner layer of the animal.

The hydra has two different methods of reproduction. In the simpler method the hydra develops a little bud at first composed of cells of the outer layer. In a few hours there is a budding or out-pushing of the cells both of the outer and the inner layer. Soon tentacles appear and later the little hydra separates itself from its parent. In the more complex method of reproduction, the hydra produces two special kinds of cells, an egg cell and a sperm cell. When the egg cell is fully developed it is joined by the sperm cell, and fertilization takes place very much as it does in flowering plants.

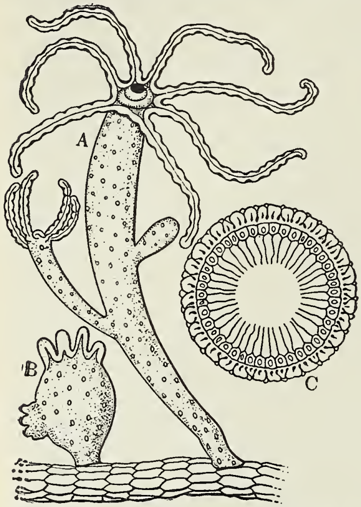


Fig. 343. *A*, a hydra stretched upward; *B*, in a contracted condition; *C*, a section of its central cavity.

Summarize briefly how the hydra performs the seven life functions.

Spiny-skinned animals that live in salt water. There are more than 4500 known kinds of these spiny-skinned animals. Sea urchins, sea cucumbers and starfish are members of this group. As a special project you might find out how these animals carry on the life functions.

Starfish are the enemies of clams and oysters. As their name would indicate, starfish are shaped like five-pointed stars. They fasten their arms on the shell of the clam and pull, sometimes for hours, until the muscles of the clam grow tired and the shell opens. Then, if you please, the starfish turns its stomach inside out, pushes it out through its mouth, surrounds the softer inside part of the clam, and digests it.

Worms, the friends and foes of man. Worms are classified into three groups, round, flat, and segmented. Although there is space here to consider only one type of worm in detail, you should remember that there are several thousand kinds of worms, some of which live in the sea, some on land, and some as parasites in plants and animals. The names of some of these parasitic worms are probably familiar—the hookworm which is feared throughout the southern part of our country; the liver fluke that causes the death of millions of sheep each year; the gapeworm that causes the death of so many chickens; and the tapeworm which grows both in animals and in man.

The earthworm is one of the most widely distributed of animals. It is found in the tropics and in temperate regions; in low land and even on the sides of mountains. It is known by a number of names—earthworm, angleworm, and fishworm. Since most of its enemies are abroad in the daytime, the earthworm does not come out of the ground in the daytime unless it is forced out by water. No doubt you have noticed earthworms crawling on sidewalks or on the ground after a heavy rain. As the water from a heavy rain drives the air out of the soil, the earthworm must come to the surface of the ground to breathe. An earthworm does not have breathing organs; oxygen from the air in the soil is absorbed by the blood vessels in the skin. What process is involved in this kind of breathing?

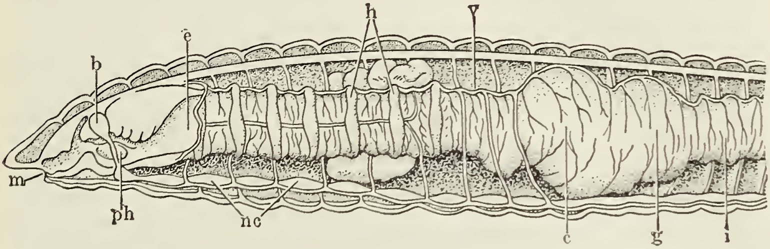


Fig. 344. Diagram of the body of an earthworm: *m*, mouth; *b*, brain; *nc*, nerve cord; *h*, contracting blood vessels or "hearts"; *e*, esophagus; *ph*, pharynx; *c*, crop; *g*, gizzard; *i*, intestine; *v*, blood vessel.

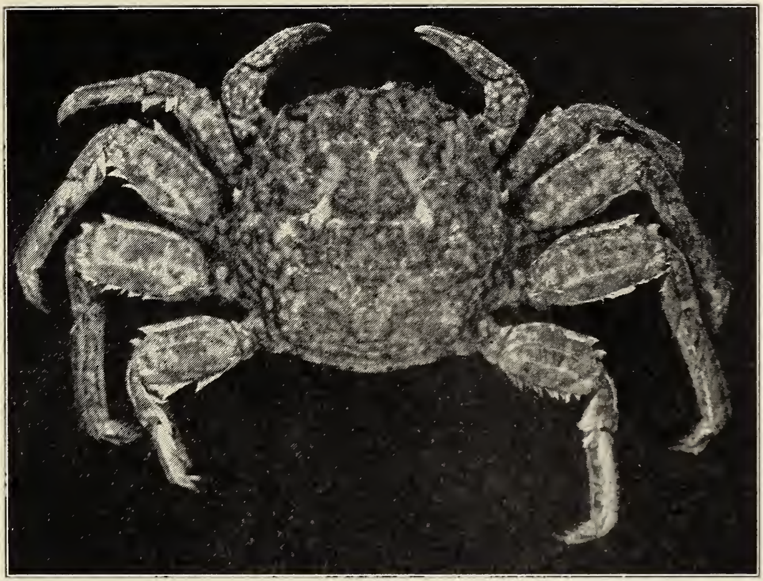
The body of the earthworm is in the form of a tube. Observe (Fig. 344) that the body wall consists of an outer skin, an inner skin, and two relatively thick layers of muscle, one running around the body and the other lengthwise. The earthworm also has organs of digestion and a system of blood cells which permits the circulation of blood through its body.

A few of the blood vessels in the earthworm expand and contract, thus serving the same purpose as the heart does in more highly developed animals. Find these on the diagram. Along the lower part of the body cavity are light-colored threads, the nervous system of the animal. These threads end in a tiny knot near the mouth. This tiny knot, the center of the nervous system, corresponds to the brain in higher forms of animal life. Did any of the animals you have studied up to this point have as many organs as the earthworm? Explain why the earthworm is higher in the animal scale than the amoeba, the paramecium, or the hydra.

The earthworm is a vegetarian for the most part, though it has been known to eat meat. It seems to be especially fond of cabbage and celery. As it burrows holes through the ground, soil passes through its body. Organic matter from the soil is absorbed during the process. This burrowing loosens the soil, permitting water and air to circulate through it; thus, this lowly animal is a valuable aid to the farmer and the gardener. The earthworm comes out for food at night. It does not come entirely out of the tunnel which it has made lest it should lose its way and thus be compelled to dig another tunnel to escape from its enemies. If you want to catch an earthworm while it is out looking for food, take care to walk softly, lest it feel the vibrations caused as you walk and withdraw quickly into its hole.

You have all watched an earthworm move. It thrusts forward one end and then draws up the other end. The next time you see an earthworm, observe its movement carefully.

The earthworm has an interesting method of reproduction. You have noticed the band, or girdle, around its body near the middle. The girdle secretes material which forms into a case or capsule. By vigorous contractions of the body of the earthworm, the case is moved toward the head. As it passes along the body, eggs are deposited in the case. The case is closed as it passes over the head of the earthworm and serves as an incubator in which the eggs hatch. These cases, which look like a grain of wheat, may occasionally be found in the soil during May and June.



Courtesy William Beebe

FIG. 345. Crabs, such as the one shown, live in shallow salt water. How many pairs of legs does a crab have? Crabs are classed with lobsters, shrimps, barnacles, etc., as crustacea, one of the classes of animals under arthropods.

PROBLEM: WHAT ARE THE CHARACTERISTICS OF THE LARGEST GROUP OF ANIMALS?

The word *arthropods* is worth learning. It is the only good name for the largest of all animal groups; in it are more than half a million known kinds—more than all the other kinds of animals put together. Crabs (Fig. 345), lobsters, thousand-leggers, spiders, and the great army of insects belong to this group.

The word arthropods means "jointed-footed" animals. If you will look at the leg of a crab or examine the leg of a fly or a wasp under the microscope, you will see these joints. The skins of arthropods contain a substance which gives these animals a hard, external skeleton which protects them from injury. You know how hard the skin of a crab is and how tough the outside of a beetle is. While growing, arthropods shed this hard skin several times. Another characteristic of these animals is that most of them change in form in passing from the egg stage to the adult stage, that is, they undergo a *metamorphosis*.

Man's keenest competitor for the food supply of the world. The kinds of insects in the world far outnumber all other kinds of living animals. About 400,000 kinds are known. Some of them, like the bee, aid us by carrying pollen from one plant to another. Others are helpful because they keep in check harmful insects which are enemies of trees and crops; for example, the ladybug eats insects on plants and another insect attacks and eats the corn borer.

The silk moth produces the raw material for the silk of the world. The work of the honey bee in furnishing honey and wax is mentioned in the earliest records of history. Shellac is made from a gum secreted by an insect in India; a brilliant scarlet dye (cochineal) is made from the bodies of certain female insects native to Mexico, Central America, and parts of South America.

Certain other insects are so harmful and destructive that they are pests. You are of course familiar with the mosquito, the fly, and similar insect pests that live largely on the blood of other animals. Flies and mosquitoes, as you know, carry disease to human beings and to animals. The common "moth" destroys many dollars' worth of clothing each year. White ants in tropical countries have been known to eat the wood in buildings until the hollow shell which remained, crumbled and fell.

Still other insects feed on the crops of the world; these insects are man's keenest competitors for the food supply of the world. You have learned about these insect enemies of plants (page 563) and how man attempts to control them.

What is the structure of insects? The name insect, meaning "cut into," comes from the fact that the body of every insect is divided into three parts: *head*, *thorax*, and *abdomen* (Fig. 346). Insects have one pair of feelers (*antennae*) attached to the head; they have three pairs of legs, and usually two pairs of wings. They breathe through tubes called *tracheae*, which open to the surface along the sides of the abdomen.

By the action of a tube-like heart, a light-colored fluid is forced through the body. This fluid does not flow in tubes but is distributed freely through the body. The nervous system of insects is more highly developed than that of any other animals which you have studied thus far. Do protozoa have any special nervous system? They do, of course, respond to heat and light and touch. In the hydra there are certain cells more sensitive than others. In the earthworm there is a nerve center that corresponds to a brain. In insects there are a number of nerve centers. In addition to the nerve center in the head, which is the brain of the insect, there is another nerve center in the head, three in the thorax, and five in the abdomen. From these nerve centers small nerves proceed to all parts of the body.

What changes does an insect go through in its life history? An insect in its early stages is nearly always quite unlike the insect at maturity. Let us consider the four changes (metamorphoses) that an insect may go through from the egg to maturity. If an insect passes through all four stages, its metamorphosis is said to be complete; if there are less than four distinct stages, as in the life of cockroaches, plant lice, and grasshoppers, the metamorphosis is said to be incomplete.

The metamorphosis of the silk moth is complete. The female silk moth lays some three hundred *eggs* and then dies. From each egg a light-colored, hairless caterpillar, called the *larva*, develops. The larva has a great appetite. It eats many mulberry leaves and stores up food material for its later stages, which represent a development in form rather than in growth. The larva grows until it is about two inches long; during this time it sheds its skin four times. At the end of about four or five weeks it spins a silk cocoon about itself and becomes much less active. While in the cocoon it is known as a *pupa*, or *chrysalis*. In about two or three weeks more a pale *moth*, that has developed from the pupa, eats its way out. This moth, in turn, lays eggs and dies.

The series of events which occur between the hatching of an egg and the death of the adult silk moth is known as the *life history* of the silk moth. The life history of each kind of insect is much like that of the silk moth.

Insects as social creatures. In spite of the simple nervous system of insects, many kinds possess highly developed instincts and seem to exhibit intelligence. This is particularly true of the bees, the ants, and the wasps. These animals live together as a social community, the organization of which is fascinating to study.

Life within the beehive. A colony of bees usually consists of one *queen* bee, a few hundred *drones*, male bees, and several thousand *worker* bees, which are female bees that do not lay eggs.

The queen is almost a prisoner; she does nothing except lay eggs, sometimes as many as three thousand in one day. The fertilized eggs develop into workers; unfertilized eggs develop into drones. Since the drones do no work, they are driven out of the hive by the workers.

The worker bees divide the work of the colony. Some of these bees gather the food, which is pollen and nectar from flowers. The nectar is brought back to the hive in the body of the bee and is deposited in the cells of the hive as a thin liquid. The workers fan this liquid with their wings for hours until it has thickened to *honey*. The wax of which the cells are made is manufactured in the bodies of the workers. It oozes from the undersurface of the abdomen of the bees and hardens into thin plates. The cells are regular in size and are designed to fill the space completely. Most of the cells are made for the storage of honey, but others serve as cradles for the young bees.

The queen lays one egg in a cell, and in three days it hatches into a tiny larva. Some of the young workers act as nurses. At first they feed the young bee on bee-jelly which is a material partly digested in the body of the nurse bee before it is fed to the young bee. Later honey is used to feed the larva. After a few days the larva is sealed up in its cell where it passes through the pupa stage. When the pupa has developed into an adult bee, it eats its way out of its cell and takes its place in the hive serving as a nurse bee for about two weeks before it goes out to gather nectar and pollen from the flowers.

Besides performing the tasks already mentioned, some workers serve as guards at the openings of the hive; others clean out the waste materials that accumulate; still others serve as repairmen on the broken wax cells. Workers also form long lines from the openings into the interior of the hive and by beating their wings cause a current of air which ventilates the hive.

When the community becomes too large, the workers build a specially large cell of wax. The larva that develops in this cell is fed on nothing but bee-jelly. This special diet causes the larva to develop into a queen instead of a worker. Often the old queen attacks the new queen and kills her. If the young queen is protected by the workers so that the old queen cannot kill her, the old queen leaves the hive accompanied by thousands of bees and flies away to found a new colony.

A few days after the new queen has assumed command of the hive, she starts out on her mating flight. Up into the air she soars followed by the drones. One by one the drones drop out of the race, until finally but one remains—the strongest of the males of the hive. The mating takes place in the air, the drone losing his life in the process. The queen returns to the hive with enough sperm stored in her body to fertilize the eggs she lays throughout her life.

Life within an ant hill. In many respects ants (Fig. 346) resemble bees. They live in colonies with a remarkable division of labor between the queen, the workers, and the "soldiers." The male ant lives a miserable existence. Fearful for his life, he creeps close to the queen in an attempt to hide. In certain species the male, as well as the queen, is a prisoner for life in a closed apartment.

The queen ant has been known to lay as many as sixty eggs per minute. If the queen ant loses her ability to lay the proper number of eggs, her bodyguard is overthrown and she is killed. Like the queen bee, the queen ant develops from an ordinary egg that is given special care by the workers.

Spiders. These animals are sometimes incorrectly called insects. They are not true insects, however, since they have four pairs of legs. How many pairs of legs have true insects? Furthermore, the bodies of most spiders are not definitely cut into three distinct divisions of head, thorax, and abdomen. Even though most persons dislike spiders, these creatures are in general beneficial to man. They kill a great many flies and other troublesome insects. With one foot on the edge of its web, a spider can detect the slightest movement of the web and will rush at once to the place from which the movement started and kill the entangled victim; if the movement is so strong that the spider senses it is caused by a powerful enemy, the spider rushes to a place of safety. Spiders seldom injure man. The daddy-long-legs belongs to the harmless class; it is useful to man because it feeds almost entirely on plant lice. Certain large kinds of spiders in tropical America are poisonous. Not all kinds of spiders spin webs.

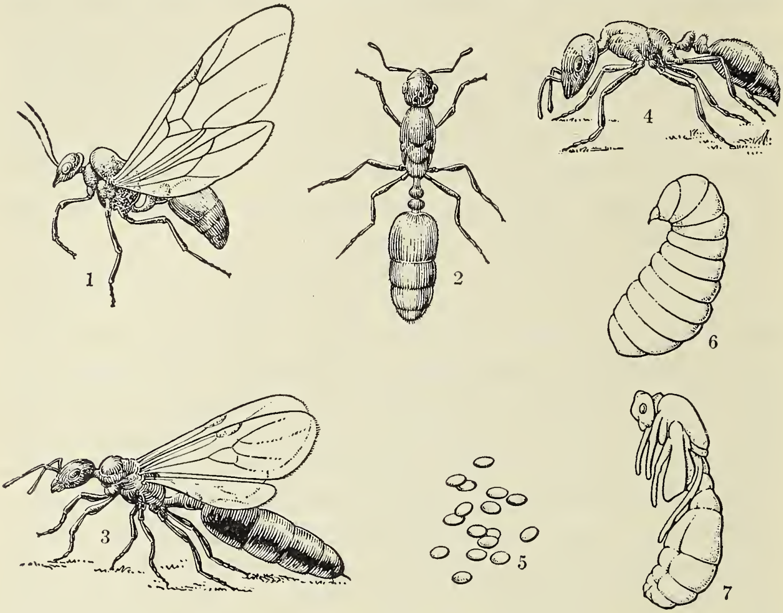
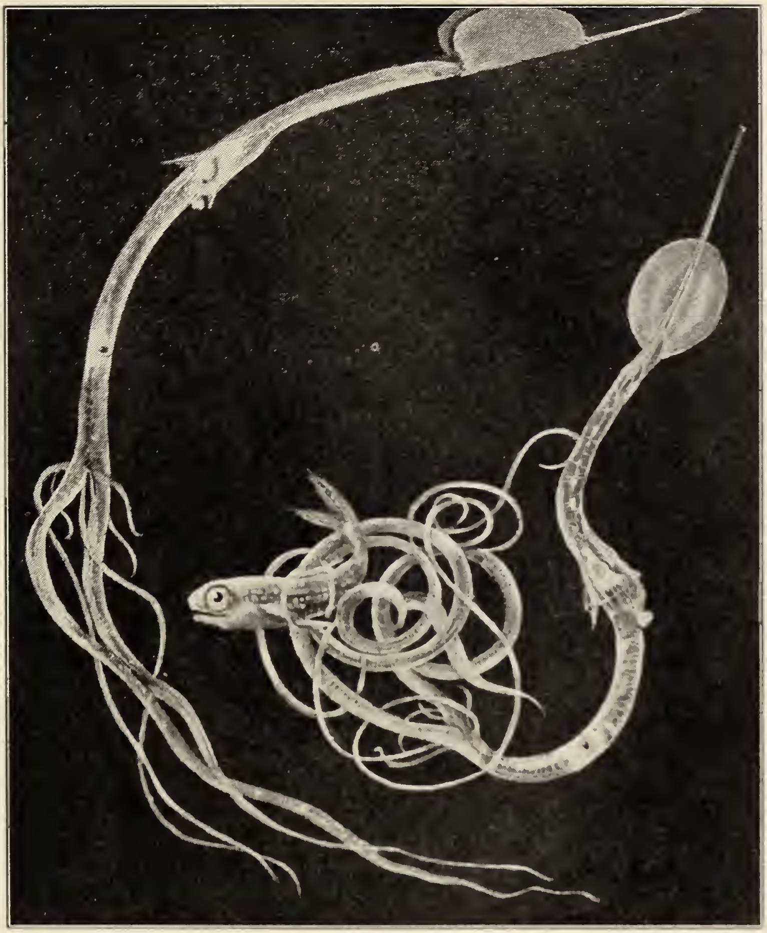


Fig. 346. The little black ant, a typical insect. Notice how clearly defined are the three parts of the insect: head, thorax, and abdomen. 1, male; 2, female; 3, female with wings; 4, worker; 5, eggs; 6, larva; and 7, pupa.

Problem: What Are the Characteristics of Mollusks?

The *mollusks* are soft-bodied animals usually living within hard shells. Among the animals of this group are oysters, clams, and snails. The abalone, found along the western coast of the United



Courtesy William Beebe

FIG. 347. Deep sea mollusks. Notice the way these squids catch fish for food. What other mollusk has long tentacles for the same purpose?

States is a mollusk. A few mollusks, such as the octopuses, the squids (Fig. 347), and the worm-like slugs which leave slimy trails in the garden, lack visible shells.

Most mollusks live in the ocean; a few, such as the mussel, also live in fresh water; others live on land. As you know, many mollusks are used for food. Name some of these. From other mollusks we get pearls and mother-of-pearl. Find out how pearls are formed.

PROBLEM: WHAT ARE THE CHARACTERISTICS OF VERTEBRATES?

Vertebrates. All the animals you have studied thus far either have had no bony structure or have had an exterior bone-like covering. We shall now study kinds of animals that have an interior framework or skeleton, part of which is a backbone. These animals are called *vertebrates.* There are five classes of vertebrates: fishes, amphibians, reptiles, birds, and mammals.

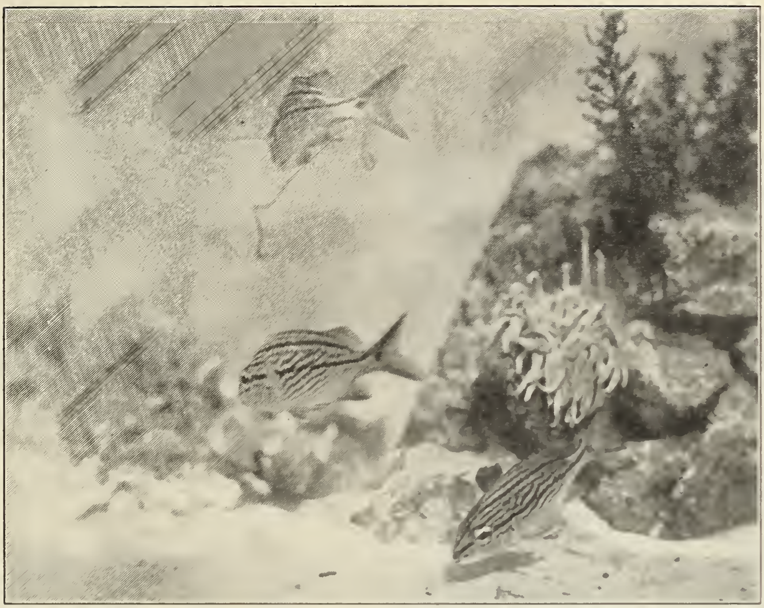
Vertebrates that live in water, fishes. One of the oldest occupations of the human race is fishing. According to the Bureau of Fisheries, the value of the fish products of the United States including Alaska is about $92,823,000 annually. In a recent year in the United States 4,807 vessels were engaged in the fishing trade. Fishing is also enjoyed as a sport by many people in all parts of the world. In our study of fishes, we are interested in their structure and in their position in the scale of animal life, as well as in their use to man.

Experiment 156. To observe the structure and movement of a fish. Look closely at the body of a living fish (Fig. 348) in an aquarium. Does the general shape of the fish make it easy for it to swim? Does the fish move rapidly? Does it use its tail? What structures do you find on the surface of the body? How does the fish use these structures?

Observe the movements of the mouth. Find the slits on the body of the fish. Do the movements of these slits correspond in any way with the movement of the mouth?

The rapid movement of a fish through the water is due to the shape of its body and the powerful muscles which operate its fins. The forward movement of a fish is affected by body twists and tail thrusts. The fins on the back and under part of the fish keep it right side up, while the side fins and the tail are used to change the direction of its movements.

A fish always seems to be chewing even if no food is present. This is due to the fact that a fish breathes by taking oxygen from



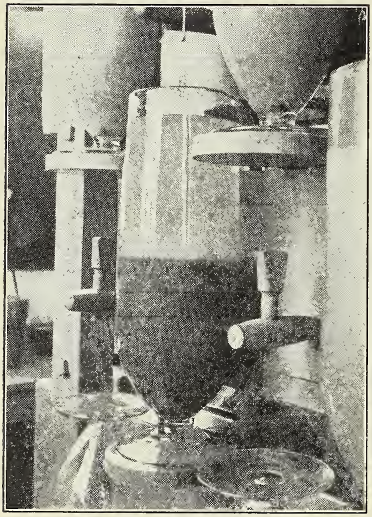
Courtesy William Beebe

FIG. 348. Study the position of the fins on these fish. How does a fish change its direction? What kind of animal is attached to the rock on the right?

water by means of *gills* located within a crescent-shaped slit on each side of its head. Each gill consists of a bony arch to which are attached thin-walled, thread-like membranes called *gill filaments.* These filaments contain tiny blood vessels that bring the blood into close contact with the water, which enters at the mouth, bathes the gills, and afterwards passes out through openings behind the head. The oxygen dissolved in the water is absorbed by these blood vessels by osmosis. The blood is caused to circulate by a heart with two communicating chambers.

The nervous system of fishes, like that of all other vertebrates, consists of a spinal cord, which extends almost the entire length of the body. The spinal cord is protected by the bony sections commonly known as the backbone. Branches from the spinal cord distribute nerves to the muscles and internal organs. The main nerve center, the brain, is an enlargement of the front end of the spinal cord.

The body of a fish is heavier than water, but, by means of an *air bladder* in the body cavity a fish can go up or down at will. When the walls of the bladder contract, air is forced out; the body of the fish then displaces less than its weight of water and so it can go down. When the walls of the bladder expand, more air enters it. Then the body of the fish displaces more than its weight of water and so it can rise in the water.



Courtesy U. S. Dept. of Commerce

FIG. 349. The United States Bureau of Fisheries maintains fish hatcheries from which young fish may be obtained to restock streams and lakes. A jar of white fish eggs is shown here.

Have you ever touched a living fish? Is it cold or warm? Fishes are cold-blooded animals, that is their body temperature is little if any higher than the water in which they live.

Fishes are reproduced from eggs (Fig. 349); some kinds of fish lay their eggs in nests; others anywhere in water. Many eggs are devoured by enemy fishes or by other animals. Were it not for the fact that fishes lay such large numbers of eggs, this class of animals would become extinct. The eggs of most fishes are small; those of certain kinds of sharks, however, are as large as a hen's egg.

What are amphibians? The word *amphibian*, meaning "double inhabitant," refers to the fact that these animals begin life in the water and later take to the land. Frogs, toads, salamanders, and mud puppies are members of this group of animals.

The life history of a frog is characteristic of amphibians. During the winter the frog remains dormant in the mud at the bottom of a pond. In the spring the female frog lays hundreds of eggs in the water (Fig. 350). In about fourteen days the eggs hatch as *tadpoles.* A tadpole resembles a fish in that it breathes through gills and has a tail. As the tadpole develops, hind legs appear and a little later, front legs; its organs of breathing also change from gills to lungs. As lungs are forming, it breathes by means of both gills and lungs and comes to the surface of the water to get air. With the change from gills to lungs and the development of legs, the tadpole becomes an animal that can live on land. It also changes its diet; while it was a tadpole it was a vegetarian; as a frog it lives largely on insects.

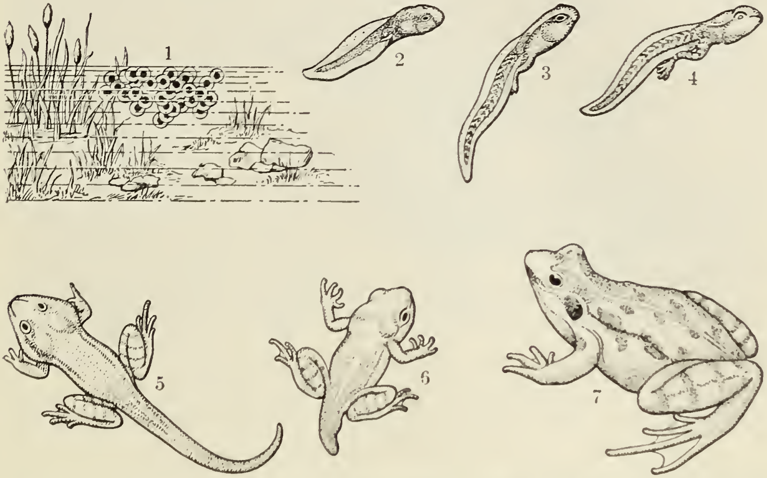
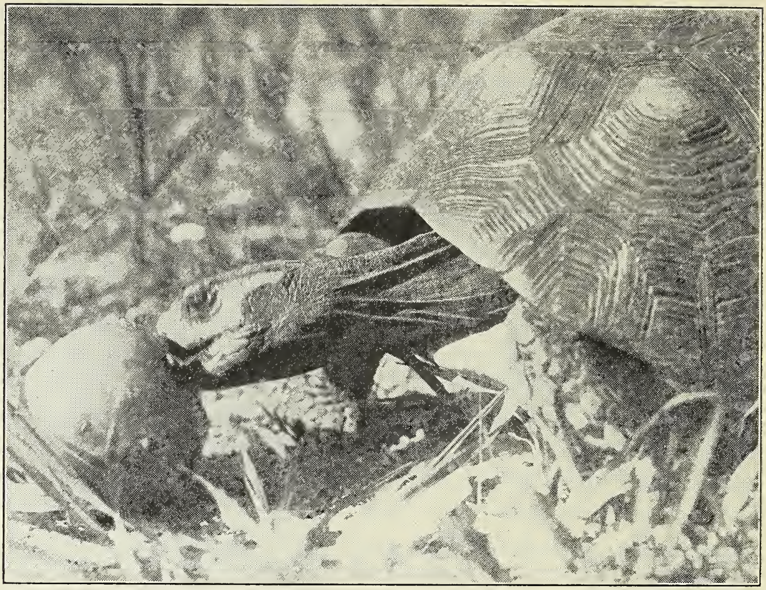


Fig. 350. What stages in the development of the frog are shown here?

The circulatory system of an amphibian is more highly developed than that of a fish. An amphibian has a three-chambered heart that distributes blood to all parts of the body through a system of arteries. The blood returns to the heart through a system of veins. The brain of an amphibian is more highly developed than that of a fish.

The toad tadpole develops completely in a month or two after hatching, but the frog tadpole does not make the complete change to a frog until the second summer. Amphibians are cold-blooded animals. Explain what this means.



Courtesy William Beebe

FIG. 351. The turtle's shell serves as a fortress. In time of danger the turtle draws his head and legs snugly within his shell and is safe. Turtles have no teeth. Food is seized and held by the jaws which have sharp, chisel-like edges.

Are all reptiles snakes? Reptiles, like amphibians, lay eggs; but they lay them on land rather than in water. A reptile does not undergo any change in form after hatching from the egg, as an amphibian does. It breathes by means of lungs from birth. A reptile has a scaly skin; an amphibian never has. In fact, in many ways a reptile resembles a bird more than it does an amphibian. The scaly skin which covers the feet of a bird, e.g., a chicken, resembles the skin of a reptile; the eggs of a reptile, too, are somewhat like those of a bird in size and they are also encased in a hard, leathery shell. Reptiles are cold-blooded animals, and most of them have a three-chambered heart.

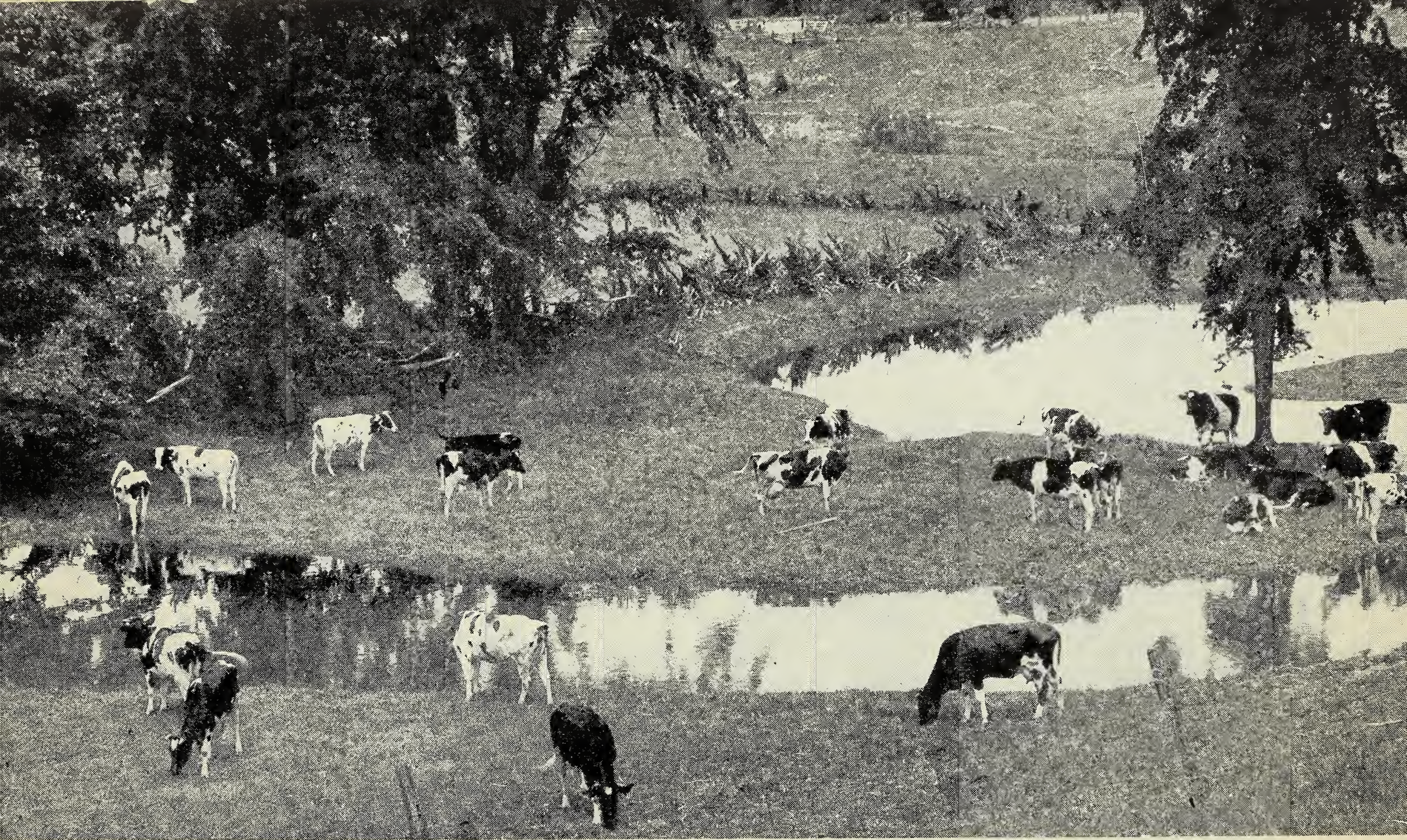
Reptiles (Fig. 351), as a class, present a variety of types, from small worm-like snakes a few inches long to giant turtles weighing a half ton or more, and to alligators and crocodiles reaching a length of thirty feet. Reptiles live on land, in salt water, and in fresh water. Most of them are harmless, and many are very useful because they eat insects, mice, snails, and other pests. Some, such as turtles, are used for food in our own country, and certain others, such as lizards, are used for food in tropical countries. The skins of certain reptiles are used for shoes, purses, and the like. Name one reptile whose skin is useful. Only a few kinds of snakes are poisonous; those found in the United States are the rattler, the copper head, the water moccasin, and the coral snake.

Are all birds useful? Most birds are welcome visitors; they are beautiful little creatures and their songs delight our ears (Fig. 352). Some of them, like the sparrow, stay with us the entire year. Others, like the robin, go south for the winter; we look for their return as one of the most welcome signs of spring.

Have you ever watched a pair of birds build a nest? What materials did they use? No doubt you have also seen birds gathering their food and perhaps have watched them feed their young. Let the class choose a bird common to your section of the country. Describe its appearance; the way in which its body is constructed; the food it eats; the kind of nest it builds; the way it cares for its eggs; and its method of taking care of its young. A bird is a warm-blooded animal. All the others that we have studied so far in this chapter, are cold-blooded.

A large part of the food of most birds consists of insects harmful to vegetation. In this way birds are of great use to man. Even the crow, which is guilty of pulling up young corn shoots, eating the ripe corn from the shock, and flying off occasionally with a young chicken, has been shown to make about twenty-five per cent of its diet on insect food. Some kinds of birds eat larger animals than insects; for example, the owl eats mice, rats and rabbits and also chickens.

The English sparrow, which was introduced into our country in 1850 for the purpose of exterminating insects, has proved almost as troublesome as beneficial. It drives away many native birds and destroys their nests; it also feeds on grains and tender garden plants.



Courtesy International Harvester Co.

FIG. 352. Think of as many ways as you can by which these animals are of service to man. Are they mammals?

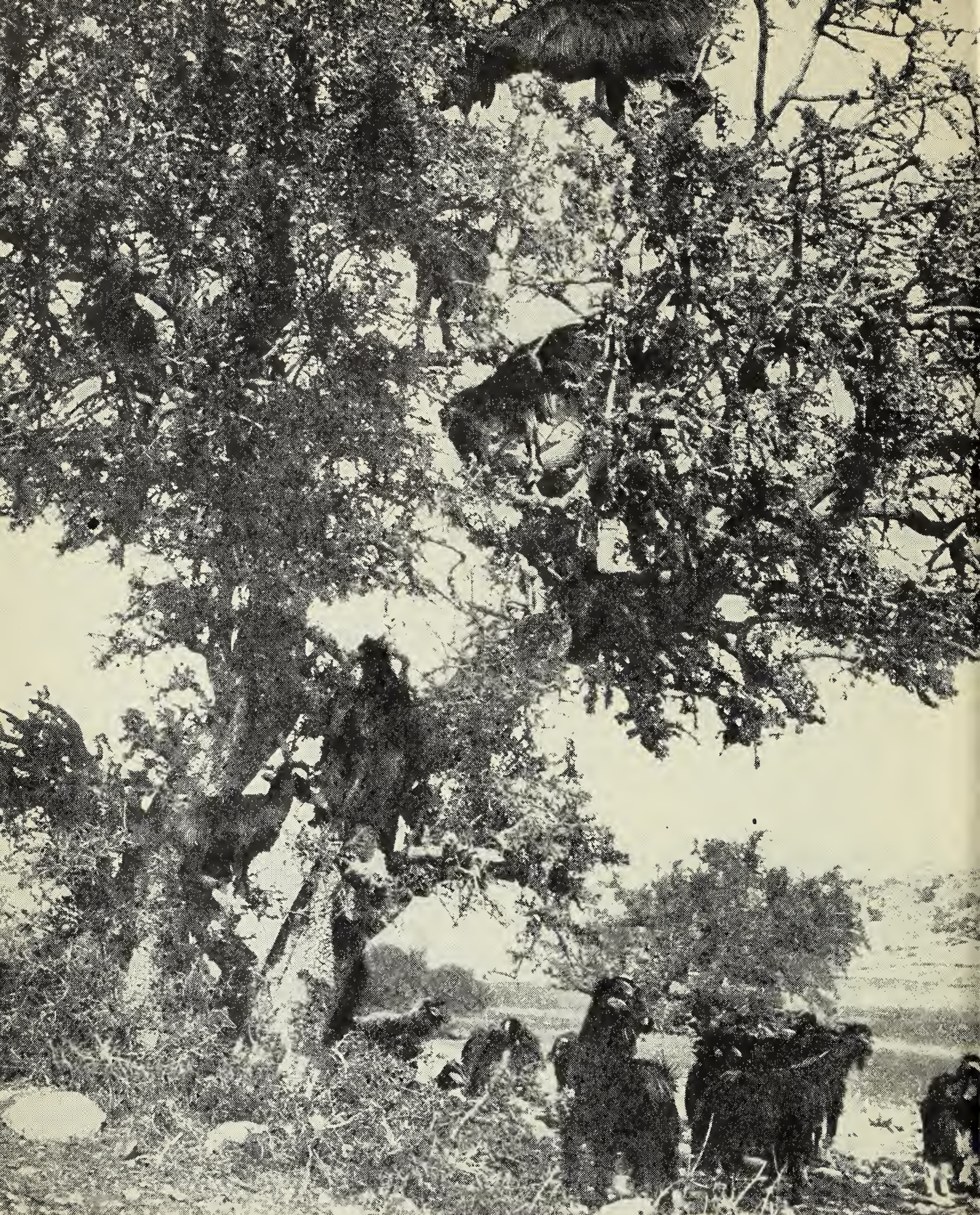
Certain varieties of birds are useful to man because they provide him with food in the form of poultry and eggs. In the United States in a recent year these products were valued at more than $437,190,000.

Every part of a bird's body is adapted for flight. The streamed lines of its body offer little resistance to the air. Its flexible neck helps in balancing. The slender, hollow, air-filled bones and the few heavy joints make birds light in weight. The arrangement of wings above the center of gravity of the body removes the danger of tipping over sidewise. The feathers of most kinds of birds are oiled by a secretion from a gland near the tail. The bird uses its beak to spread the oil over the feathers. It is thought that this oil helps to make the plumage of birds waterproof, particularly in the case of birds such as gulls, that live part of the time on the water. Water birds also have a thick, fine coat of down on the under-sides of their bodies. Birds shed and re-grow feathers at least once a year. Wing feathers are shed gradually so that the wings may always be able to sustain the bird in flight.

What are mammals? To *mammals* belong such plant-eating animals as the goat (Fig. 353), horse, cow, sheep, pig, elephant, buffalo, deer; and such flesh-eating animals as the dog, cat, lion, tiger, leopard, grizzly bear, walrus, sea lion, panther, and wolf. Mammals are warm-blooded animals. They are known by the following characteristics: (1) they give birth to their young instead of laying eggs; (2) they nourish their young with milk; (3) at maturity hair covers either the entire body or parts of it; (4) they have a muscle (*diaphragm*), that aids in breathing; and (5) they have highly developed digestive, respiratory, circulatory, and nervous systems.

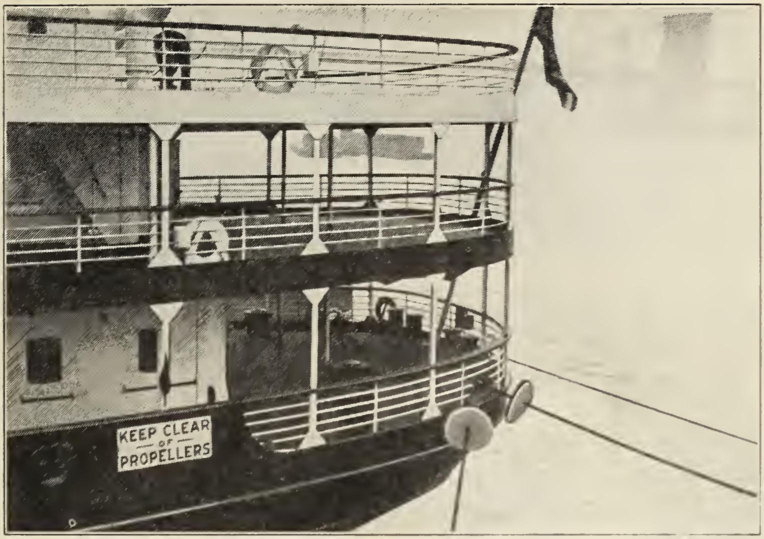
From mammals man secures much of his food and clothing. Certain of them are used by man as beasts of burden and the dog frequently serves man as companion and protector.

Man has enemies, however, among the mammals. To be sure, the fierce, flesh-eating mammals are gradually being pushed back into the diminishing frontiers; but there is still one enemy that stays right with us—the common rat (Fig. 354). He is an enemy because of his filthy habits and because he destroys



Courtesy Dr. David Fairchild & National Geographic Society

FIG. 353. This photograph of goats in an argan tree in Northern Africa appeared in *Exploring for Plants*, by Fairchild. It shows very clearly the efforts animals will make to obtain food in a rather barren country.



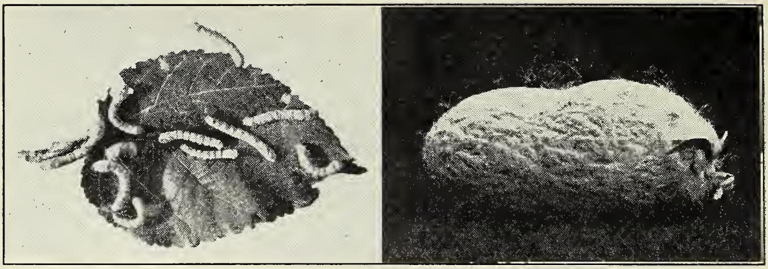
Courtesy Ward Line

FIG. 354. This ship uses rat guards on the hawsers while in port to prevent rats from entering or leaving.

food that man provides for himself. The rat leaves unused food in all sorts of places where it may decay and become offensive. He carries disease germs that may be communicated to man. He destroys enormous quantities of grain, prepared food, and clothing. He sometimes kills poultry and small animals, and has even been known to attack persons who were ill and alone. In fact, the rat is such an enemy of mankind that he should be exterminated. How can we accomplish this? Perhaps you can suggest means of ridding your community of this enemy.

PROBLEM: WHAT RAW MATERIALS DOES THE ANIMAL KINGDOM FURNISH MAN?

We have said that animals contribute to man's welfare not only as beasts of burden but also as the source of raw materials for many of the necessities of life. You will recall from your study of history that the North American Indians were almost entirely dependent on animals for food, clothing, and shelter. In fact,



Courtesy Corticelli Silk Co.

FIG. 355. At the left silkworms are shown feeding on a mulberry leaf. At the right a silk moth is emerging from its cocoon.

the wealth and welfare of certain tribes were dependent on the number of wild animals they could kill. A study of a few of the more important animal products will show that even in modern times and among highly civilized people animals contribute abundantly to man's welfare.

How is natural silk obtained? All natural silk is produced by the silkworm, the larva of the silk moth. We shall now relate briefly just how the silkworm produces silk. Running the entire length of a silkworm's body are two glands which have a common opening (spinneret), near the mouth. These glands secrete a jelly-like substance that hardens when it reaches the air. It is this hardened secretion that forms the silk thread. After feeding for some time on its favorite food (Fig. 355), the fully grown larva is ready to change to the pupa stage. It then begins to spin its cocoon. The secretion from both glands is sent out through the spinneret in the form of a single continuous thread. For three days the worm continues to spin this thread, which is usually eight hundred to twelve hundred yards in length. This thread forms the cocoon in which the insect passes the pupa stage. As you know, if a cocoon is left alone for a month, the pupa develops into a moth, which makes a hole through one end of the cocoon and comes out. In doing so, it cuts the silk threads and destroys their commercial value. Consequently, the moth is not permitted to emerge from the cocoon unless it is needed for laying eggs from which more silkworms may be raised.

The cocoons which are to be used for silk are exposed to steam or dry heat, which quickly kills the moth before it has a chance to destroy the threads. After this, the cocoons are washed in soap and water to remove the sticky substance from the silk. Then a worker catches with a brush the ends of threads from several cocoons, joins them together, and winds them on a reel. Machines weave the silk thread into cloth in factories. Silk fiber is in great demand for clothing because it is so strong that it can be woven into very beautiful, thin material. The smooth surface of silk fiber makes silk cloth remain clean longer than other fabrics.

From what animals do we obtain wool? Wool, one of the materials most widely used for clothing, is also an animal product. As you know, it is the long hairy covering of sheep. There are many breeds of sheep. Many of our western flocks are merinos, bred from the original Spanish merino. This breed of sheep is known for its long, fine, and abundant wool, and for the fact that it is hardy and easily cared for.

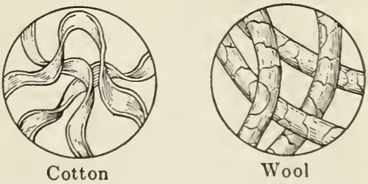


Fig. 356. Cotton and wool fibers as seen under a microscope.

In late winter or early spring sheep are sheared either by hand or by machinery. After shearing, the wool is washed and dried, carded, spun into yarn, and woven into cloth. Woolen cloth cannot always be distinguished by the touch from cotton cloth. Wool fibers can easily be distinguished, however, when placed under a microscope (Fig. 356). Cotton fibers are flat, twisted threads, while wool fibers are round and jointed. Notice the tiny scales that overlap each other. Wool fiber has three advantages for use in clothing in cold climates: it is a poor conductor of heat; it absorbs moisture without feeling wet; and water does not evaporate from it quickly thus chilling the body. Explain why bathing suits are usually made of wool.

There are, in the United States, more than a thousand woolen mills. Our Department of Commerce estimated recently that the annual wool production of the world was nearly 3,000,000,000 pounds, of which 301,060,000 pounds were furnished by the United States.

What animals have fur? Among our most valuable fur-bearing animals are the sable, the ermine, the otter, the beaver, the seal, and the squirrel. Others, which are often trapped by boys in the country, are muskrats, foxes, skunks, and minks. Occasionally the young trapper is fortunate enough to capture a raccoon.

After the hide is stripped from an animal, it is stretched on a board or frame to dry. After all flesh and fat are carefully scraped from the skin it is washed and then dried in hardwood sawdust. Furs are made into garments or used as trimming. Some furs are dyed before use; others are used in their natural color.

How leather is tanned. Leather is manufactured from the skins of animals. If hides are to be stored, they must be rubbed with salt to keep them from being injured by bacteria. Before hides can be used to make leather, the hair is removed by soaking them in a strong solution of calcium hydroxide, that is, lime water, to loosen the hair so that it may be scraped off easily. The inside of the skin is also scraped to remove any remaining flesh. The hides are then placed for a number of weeks in tanning vats, containing water and ground tan bark, the tannin from which slowly changes the hides into tough leather. Tannin is a substance found in the bark of certain trees, especially the oak, and in the heartwood of quebracho trees. After the leather is taken from the tanning vats, it is thoroughly washed and greased, and sometimes colored.

How glue is made. Most of us have little idea of the vast amount of glue used in modern life. Great quantities are used in cabinet making, stairwork, builders' millwork, and in mending. It is used also in binding books, in sizing walls and paper, in covering polishing wheels in foundries, and for many other purposes. It is interesting to note that American glue was first manufactured by Peter Cooper in 1837. You may have heard of Peter Cooper in connection with the early steam locomotives used in this country.

Glue is a by-product of packing plants and fisheries. It is an impure gelatin with very strong adhesive force. It is made from bones, hoofs, horns, bits of hide of animals, or from fish refuse.

The bones are first crushed and heated to extract the fat. If bits of hide are used, they are soaked from ten to forty days in lime water or in caustic soda and sulfuric acid to remove the hair and blood. After this they are washed in water and dilute hydrochloric acid, and then boiled in water until jelly-like, that is, gelatinous.

Glue made from the refuse of fish has strong adhesive properties, but has a very disagreeable odor unless some substance is added to destroy it. Liquid glue is made by treating ordinary dry glue with nitric or acetic acid.

Fertilizers from packing house wastes. As you have learned, if soil is to remain fertile, certain elements must be added to it. The more important of these elements are nitrogen, phosphorus, potassium, and calcium. These are added to the soil in the form of phosphates of calcium, and compounds of nitrogen and potassium. Dried blood and other packing house wastes are used to supply part of the nitrogen compounds for fertilizers. Ground bone contains some nitrogen and also some calcium phosphate.

Food from animal life. Most persons eat meat, fish, poultry, shellfish and other animal products as well as plant products. The United States Department of Agriculture has estimated the average number of animals annually slaughtered under government inspection during ten fiscal years 1929–38 was: cattle, 9,411,929; calves, 5,373,053; sheep, 16,967,934; swine, 40,679,629; and 8,061,434,348 pounds of meat food products. Approximately two thirds of the meat supply is prepared under Federal inspection. When we add to this the various kinds of poultry, the dairy products—butter, milk, and cheese—eggs, fish, oysters, clams, crabs, shrimp, and turtles; we are amazed at the enormous amount of animal matter used by man as food.

In order that food obtained from animals such as meat, poultry, and dairy products, fish and sea foods may be healthful, both Federal and State Governments have passed laws pertaining to the production and sale of such foods. This legislation together with rigid sanitary inspection by both United States and state officials and even those of cities, together with modern sanitary methods of manufacturing animal food products has brought certain American foods to a high standard of purity.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

abdomen
amphibian
amoeba
antennae
arthropod
assimilation
cilia
chrysalis
circulation
cochineal
cocoon
coral
cuticle
diaphragm
drone
earthworm
gills
hydra
insect
invertebrate
irritability
larva
mammal
metamorphosis
mollusk
omnivorous
paramecium
protozoa
pupa
reptile
secretion
segment
skeleton
specialization
spider
spiny-skinned
sponge
starfish
stimuli
tentacle
thorax
trachea
vegetarian
vertebrate

Write the number of each item on your paper and after it the word that completes the statement.

1. The living matter in an animal cell is called __________.
2. An example of a one-celled animal is the __________.
3. The response of protoplasm to stimuli is known as __________.
4. A paramecium moves by means of hair-like projections called __________.
5. A paramecium is an animal of higher type than __________.
6. Some kinds of lower animals breathe by the process of __________ through the cell wall.
7. Man's greatest enemies are the animals called __________.
8. An insect has __________ body parts.
9. Animals that have an exterior skeleton are called __________.
10. Animals that have an interior skeleton are called __________.
11. The breathing organs of fish are called __________.

12. The highest class of vertebrates is called __________.

13. In the development of an amphibian breathing organs change from __________ to lungs.

Which of these statements are true? If any are false, re-state them in correct form.

14. The earthworm is a single-celled animal.

15. One class of animals is said to be higher than another class because of the number and complexity of its organs.

16. The lowest class of animal is the hydra.

17. All insects are harmful to man.

18. Spiders belong to the class of animals called arthropods.

19. Reptiles are invertebrates.

20. A spider is a higher form of animal life than a reptile.

21. The lowest of the vertebrates is the fish.

22. Fish breathe oxygen that is dissolved in water.

23. Reptiles lay eggs.

24. A frog is a reptile.

25. In modern life man is practically independent of raw materials furnished by animals.

THOUGHT EXERCISES FOR UNIT XIV

Principles of Science

State the principles of science in this unit in sentence form. One of them is: In adult life amphibians breathe by means of organs called lungs.

Questions or Problems

1. What class of animals forms coral reefs and coral islands?

2. What class of animals formed the chalk cliffs of England?

3. Why is the earthworm considered a higher type of animal than the hydra?

4. How is the earthworm an aid to the farmer?

5. Why is the spider not classified as an insect?

6. In what ways are bees valuable to man?

7. Why is it possible for a fish to float in water?

8. How does a salamander differ from a lizard?

9. In what ways are reptiles more like birds than amphibians?

10. Why are insects said to be man's worst enemy?

11. What would we be deprived of in everyday life if animal products were suddenly taken away from us?

Projects and Reports

1. If the season is right, collect some frog's eggs from a stream or pond and bring them to the class room. If the eggs are kept in water from the stream or pond and at the right temperature, the eggs will hatch. Watch the development of the eggs and young tadpoles.

2. If the season is right, collect some tadpoles from a stream or pond and bring them to the class room. Keep them in water secured from the stream or pond. Watch their development.

3. Make a list of the wild vertebrate animals (exclusive of birds) in your locality. In making your report secure pictures of the animals if possible. Describe their habits of life and tell what value they are to the community.

4. Make a list of the birds in your part of the state. In making your report, secure pictures of the birds, if possible. Describe their habits of life and tell what value they are to the community.

5. If you live near a body of water where fishing is an industry, make a report on the kinds of fish caught, methods used in fishing, and the value of the fish products to the community.

6. If there is an apiary near your community, visit it and learn all you can about bees. Make a report to the class on the care of bees, taking honey from the hives, and swarming.

7. Visit a natural history museum. Select one kind of animal for study and make a report to the class.

8. Visit a zoo. Make a list of the animals there and classify them. In your report to the class, tell from what part of the world they came.

References for Reading and Study

1. Akeley, C. E., and Mary L. Akeley, *Lions, Gorillas and Their Neighbors.* Dodd, Mead and Company.

2. Aymar, Gordon C., *Bird Flight.* Dodd, Mead and Company.

3. Barrows, W. M., *Science of Animal Life.* World Book Company.

4. Berridge, Walter S., *All About Fish and Other Denizens of the Sea and Rivers.* R. M. McBride and Company, New York.

5. Berridge, Walter S., *All About Reptiles.* R. M. McBride and Company.

6. Ditmars, R. L., and William Bridges, *Wild Animal World.* D. Appleton-Century Company.

7. DuPay, Wm. A., *Wonders of the Animal World.* D. C. Heath & Company.

8. DuPay, Wm. A., *Our Insect Friends and Foes.* John C. Winston Company.

9. Foster, G. S., *Birds and Bird Clubs.* The Christopher Publishing House, Boston.

10. Herrick, C. Judson, *Brains of Rats and Men.* The University of Chicago Press.

11. Herrick, C. Judson, *The Thinking Machine.* The University of Chicago Press.

12. Lutz, Frank E., *Field Book of Insects of United States and Canada.* G. P. Putnam's Sons.

13. Mathews, *Field Book of Wild Birds and Their Music.* G. P. Putnam's Sons.

14. Moseley, W. L., *Our Wild Animals.* D. Appleton-Century Company.

15. Nida and Holmes, *The Ladder of Life.* D. C. Heath & Company.

UNIT XV

HOW IS IT POSSIBLE TO BUILD A HEALTHY BODY?

Exploring Man's Vital Necessity, Food

Have you ever thought of your body as a well balanced, smooth running machine, which is able to grow, repair and run itself? In some ways the body may be compared to a smooth running automobile. As you know, an automobile requires fuel (gasoline) to furnish energy to make it run. A system of levers and gears transmits power from the engine to the wheels. The temperature of the automobile is controlled by the radiator and other parts of the cooling system and waste products are thrown off through the exhaust. Of course, the automobile cannot grow, repair or drive itself, but when once started, if furnished with fuel and guided, it will run continuously for many hours.

In so far as fuel and the production of heat and energy are concerned, the body and the automobile are somewhat the same. Like an automobile, your body requires food (fuel) to furnish it with heat and energy. It is kept at a constant temperature by the skin and other organs. The muscles and bones change its energy to movement. The body, however, is a still more wonderful machine. The body not only uses food for energy, but also uses food for growth and repair. From infancy to adulthood, the body continues to grow. Unless there is serious injury, each cell with the proper nourishment maintains itself in good working order throughout its life. The organs which make the body a well balanced and smooth running machine are the brain and nervous system. If the body is provided with the right kind of food and given the proper rest and exercise, it will maintain itself in good health for years.

In this unit, we shall learn why it is necessary for us to choose our food wisely and how it is digested and used by the body for growth, repair, and the production of energy. We shall learn too how the brain and nervous system make the body a smooth running and self-directed machine.

CHAPTER XXX

IS A WELL-PLANNED DIET NECESSARY TO BUILD AND MAINTAIN A HEALTHY BODY?

Do you know:

That your health is determined largely by the food you eat? Why white rats are used so often in experiments to test foods? Why you should eat a variety of foods? In what way foods containing protein nourish the body? What elements unite to form fats and carbohydrates? In what way fats and carbohydrates nourish the body? What elements are contained in proteins that are not in fats and carbohydrates?

That minerals in foods are called "chemical activators" and "regulators"? That certain foods are called "protective" foods? What vitamins are provided by fruits? What vitamin has the same effect upon the body as sunshine? That milk is made safer for household use by pasteurization? That food values are measured in calories? Why fruits should be washed thoroughly before they are eaten?

Problem: What Kinds of Food Must be Eaten to Build a Healthy Body?

Benefits of sound health. If one possesses sound health, he is apt to enjoy life and to do his work well. Some of the indications of sound health are bright eyes; a clear complexion; a strong, well-proportioned body; good posture; a cheerful and optimistic disposition; and an abundance of energy (Fig. 357). A person in sound health is able to concentrate on his work, with vigor and alertness, and can accomplish much more than if his health is poor. Such a person is likely to continue to be youthful in spirit throughout his entire life.

Why is it necessary to choose your food wisely? Since sound health is quite essential to your success and happiness, you should

Courtesy National Committee on Boys and Girls Club Work

Fig. 357. National 4-H Club health champions. The girls tied for first place in competition with one girl champion from each of seventeen states. The boy won first place in competition with one boy champion from each of fourteen other states. What evidences of sound health do these young people show?

know how to maintain your body in a healthy condition. To a much greater extent than is commonly realized, health depends upon the proper selection and the use of the right amount of food.

In the early history of our country, it was not so necessary to choose foods with great care. As every family had a garden, fresh vegetables and fruits were eaten from early in summer until late in autumn. Milk, eggs, and meat were plentiful and, when eaten with corn, wheat products, vegetables, and fruit, furnished a well-balanced diet.

At the beginning of the twentieth century, a great social change began to take place. With the growth of cities, garden space for each city family was no longer available. It became necessary to depend more and more upon grocery stores for all foods. Today it is possible to buy almost any kind of food in a can or cardboard box. In order to keep these foods from spoiling during transportation or in storage, many of them have to be preserved. Because the essential parts of many kinds of food are destroyed or damaged by the processes of preserving we must choose wisely the foods we eat if we are to remain healthy.

Can you rely on appetite as a guide in the selection of food? A child with normal, healthy parents comes into this world with a fund of vitality. A young child, fed with proper food, grows and develops a healthy body. When he becomes old enough to choose his own food, he must be careful or he will do himself great harm. Appetite is not always a reliable guide in the selection of food. The appetite or habit may suggest candy, cake, pie, ice cream, and soda water. These are not harmful in themselves, but if they are taken into the body just before meals or between meals, they are apt to destroy the appetite for body-building foods. Many times boys and girls are guided by fads which keep them from eating the right kinds of food or from eating enough food to keep their bodies properly nourished. Surely no boy or girl really wants to be unattractive and sickly? Yet many boys and girls weaken their bodies by being careless in their selection of food.

What has been learned about food from experiments? If you cannot rely on appetite or fads in selection of foods, upon what can you rely? Hundreds of experiments with animals and some with human beings have shown what foods are necessary to maintain good health.

Some of these experiments have been performed with white rats. In one such experiment, performed by Professor McCollum of Johns Hopkins University, one group of young rats was fed on a diet that contained all the kinds of food that, before 1911, were considered necessary to a balanced diet. Their food consisted of bolted wheat flour (flour from which all the coarser particles, such as bran, has been sifted); degerminated cornmeal (corn from from which the germ has been removed); navy beans, beets, turnips, cooked and dried potatoes, and beef steak. The rats apparently liked this diet. But when the rats were about one year old they were much smaller than they should have been at that age; they had thin hair and were old in appearance. They were so irritable that persons could not handle them without danger of being bitten. Since rats live about two years, their age at the time of the experiment would correspond roughly to an age of thirty years for human beings.

At the same time, another group of young rats was fed the same diet except that the wheat flour and cornmeal were made from the whole grain and in addition whole milk, that is, milk from which no part had been removed, was fed to this group. These rats retained their vigor and alertness; their coats were sleek; they were not irritable and could be handled with safety.

The diet of the first group of rats included seeds, roots, tubers, and meat. The greater part of seeds, roots, and tubers is the stored food of plants. The embryo (germ) is the active part of the corn and wheat grain. Bolted flour and cornmeal lack not only the embryo but also the coarser material of the hull.

From his experiment, Professor McCollum reasoned that whole milk and the embryo and hull of grains are essential elements in the diet of rats, and also in a balanced diet for man.

What kinds of food are necessary for a balanced diet? A diet that contains all classes of nutrients in the proper porportion is said to be a *balanced* diet. The results of food experiments show us that a balanced diet furnishes the body with the following kinds of foods: proteins, carbohydrates, fats, mineral matter, and vitamins. We shall now study each of these kinds of food as they are necessary for a balanced diet.

Experiment 157. To test a food for protein. Place three or four pieces of the white of a hard boiled egg in a test tube and add an equal volume of concentrated sodium hydroxide. Boil for several minutes. Add a very dilute solution of copper sulfate one drop at a time. What color change occurs? A violet or rose-pink color indicates that the food contains protein. Does egg white contain protein?

Test lean meat and cheese in the same way. Does each contain protein? How do you know?

What are proteins and for what purpose are they used by the body? *Proteins* are compounds that always contain oxygen, hydrogen, carbon, and nitrogen; certain proteins also contain sulfur and phosphorus. Proteins are used by the body for the growth and repair of body cells (Fig. 358). As you know, these cells are continually being broken down and must be repaired. During rest, and even sleep, the cells of the brain, nerves, heart, kidneys, etc., require proteins.

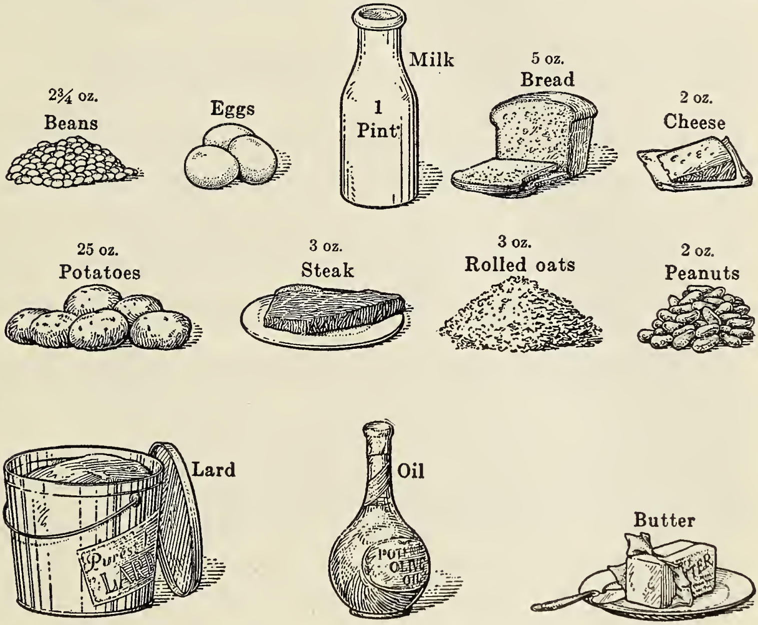


Fig. 358. Each food in the two upper rows contains approximately 15 grams of protein. What other foods besides the three shown in the bottom row contain chiefly fat?

Food experiments indicate that healthy growing animals convert 65 per cent of the protein in milk and eggs into proteins which can be used by the body cells. The proteins in meat cannot be used as easily by the body as the proteins of milk and eggs. The proteins in grains are even less easily used by the body than those in meats. Peas and beans provide proteins that are still less easily used by the body. It is thought that a diet consisting of milk, eggs, meat, and green leaves, with tubers and cereal grains, will provide proteins for all of the different kinds of body cells.

Certain plant products used as food, such as beans, peas, and nuts, contain much protein. Grains such as wheat, rye, barley, and corn contain smaller amounts. The leaves of certain kinds of plants are rich in protein also. Milk, eggs, lean meat, fish, and cheese are animal products that are rich in proteins.

Experiment 158. To test a food for fat. Secure a piece of white glazed paper (a sheet of writing paper will do). Warm a piece of fat meat and by rubbing it on the paper make a spot about half the size of a silver dollar. Continue to warm the food and rub it on the paper until the paper is darkened. Hold the paper up to the light. Does the light shine through it? The translucent spot indicates that the food contains fat. (If glazed paper is wet with water, the spot will not be translucent when held up to the light.)

Test oil and grease in the same manner. It is not necessary to warm them before rubbing on the glazed paper. Do they contain fat? How do you know? Test also nuts and potato.

What are fats and for what purpose are they used by the body? Fats are compounds of carbon, hydrogen, and oxygen. They occur in every animal and vegetable tissue and are insoluble in water. When digested, fats supply the body with energy in the form of heat and with energy needed for muscular activity (Fig. 358). During digestion, a part but not all of each kind of fat is changed into a sugar which is used by the body to supply energy.

As fat may be stored up in the body, it may be thought of as stored food which may be used later to supply energy. During illness the body uses this stored food. Fatty tissues, however, do not function as muscular tissues do, and so a large amount of fatty tissue is harmful to health.

Certain food experiments indicate that fats supply the body with an acid which is necessary to maintain life. So necessary is this acid that if the body were furnished with every other necessary substance except it, life would be extinguished.

The chief foods that contain fats are oils, butter, and the fat of meats. Nuts also contain a large amount of fats (Fig. 358).

Experiment 159. To test a food for carbohydrates. A. Starch. Place a few small pieces of white bread in a beaker and boil for five minutes with enough water to cover the bread. Allow it to cool. Add a few drops of iodine solution and stir with a glass rod. A blue color on the addition of iodine indicates the presence of starch. Does bread contain starch?

Test potato and rice for starch. Do they contain starch?

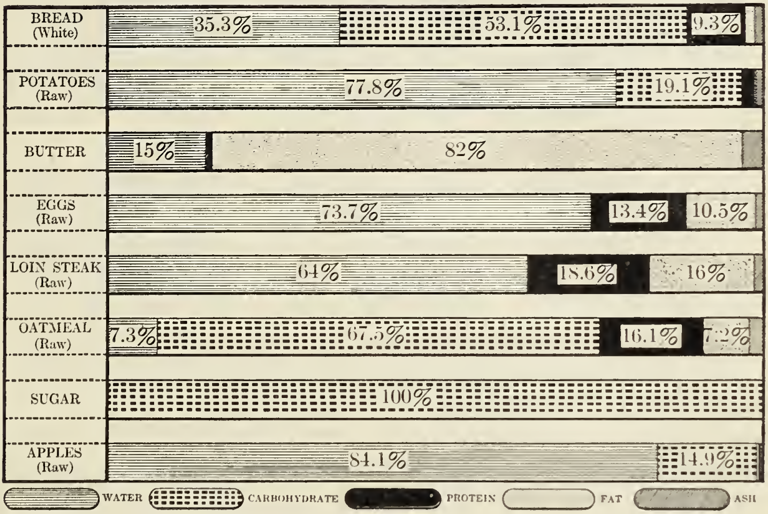


Fig. 359. Percentage composition by weight of some common foods, very small per cents are not given. Each bar in the graph represents 100 per cent.

B. Sugar. Add a little corn syrup to a test tube one-fourth full of water. Heat to boiling. Add 5 cc. of Haine's solution and again heat to boiling. Is there any color change? A yellow or brick red color on the addition of Haine's solution indicates sugar. Does corn syrup contain sugar?

Test honey and a raisin for the presence of sugar. Does each contain sugar? Cook rice, beans, and potato, and test each one.

(Haine's solution is made as follows: 10 g. copper sulfate, 45 g. potassium hydroxide, 100 cc. glycerin, 875 cc. distilled water.)

What are carbohydrates and for what purpose are they used by the body? *Carbohydrates* are compounds of carbon, hydrogen, and oxygen. What other kind of food is made up of these three elements? Starches and sugars (Fig. 359) are examples of carbohydrates. Carbohydrates furnish the body with energy.

In the process of digestion, all starches and sugars are converted into simple sugar (*glucose*). Glucose is absorbed by the blood vessels in the walls of the intestines. The blood from the intestines then passes through the liver, where glucose from the blood is stored. As the food-laden blood passes through the liver, a large part of the glucose is changed into a compound called *glycogen* and stored in the liver cells. The blood, with a reduced load of sugar, after leaving the liver circulates through the body. As the sugar in the blood is used up by the body cells, the liver begins, little by little, to release some of this glycogen into the blood stream. In this way the blood at all times contains about the same amount of sugar.

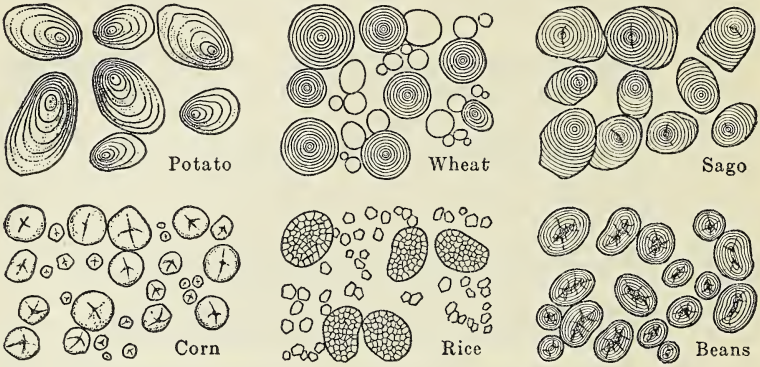


FIG. 360. Starch grains from various foods. The rice grains are magnified 300 times, the others 220 times.

Glycogen is made and stored in a similar way by other tissues of the body. The muscles, for example, store up glycogen, releasing it to the blood as needed.

Starch is a carbohydrate found in the cells of certain grains and vegetables (Fig. 360). Bread, potatoes, rice, cornmeal, tapioca, and beans contain starch. Most fruits, corn syrup, maple syrup, cane sugar, beet sugar, and honey contain sugars. Milk contains an easily digested sugar known as *lactose*.

How do we measure food values? Food values are measured in calories. You will recall that one calorie (page 359) is the amount of heat required to raise the temperature of one gram of water 1° C. This unit is the small calorie. Another unit of heat measurement is the *large calorie*, the amount of heat required to raise the temperature of one kilogram (a little more than a quart) of water 1° C. The large calorie is 1000 small calories.

The large calorie is the one used to measure the energy produced by foods when digested and absorbed by the body. So you see food values in terms of energy are measured by the amount of heat the food would produce if it were burned outside the body.

Calories in Different Kinds of Foods

Kind of food	*Calories per gram*	*Calories per pound*
Protein	4.1	1860
Carbohydrate	4.1	1860
Fat	9.1	4217

How many calories does the body need each day? The selection of foods, based on the energy the body may get from them, is the chief factor in planning a balanced diet. Of course, all persons do not need each day the same kinds of foods or the same number of calories. A man at heavy labor needs from 5000 to 6000 calories per day; a carpenter from 2700 to 3400 calories; while an office worker or student only from 2000 to 3000 calories. Boys between twelve and sixteen need about 3000 to 4000 calories. In general girls do not need quite so many calories as boys. Boys playing football or other strenuous athletic games need 5000 to 6000 calories each day.

Experiment 160. To test a food for mineral matter. Place a small piece of lean meat in an iron spoon and heat over a Bunsen burner until the organic matter is completely burned. The substance which remains is mineral matter known as ash. Test two other foods for mineral matter.

How can you tell whether a food contains mineral matter?

What are minerals and for what purpose are they needed by the body? Several minerals are necessary to the proper growth, repair, and regulation of the organs of the body. Some of these are metals, such as copper and iron, which are taken into the body in compounds known as mineral salts. Many foods contain these mineral salts and when eaten and digested the elements making up the mineral salts are used by the body.

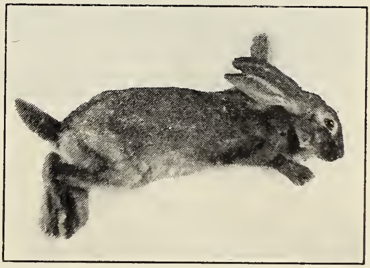
Eleven mineral elements are thought to be essential to the proper growth and nutrition of the body. These are sodium, potassium, calcium, magnesium, chlorine, iodine, phosphorus, iron, copper, manganese, and sulfur; other elements, cobalt, fluorine, nickel, silicon, and zinc, are always found in the body but their specific use is unknown at present. Calcium and phosphorus are necessary to produce proper tooth and bone structure. Iron is a part of the red corpuscles of the blood. Iron cannot be absorbed by the body and become a part of the red corpuscles unless copper is present; just what the copper does is unknown at present. Iodine is necessary for the proper functioning of the *thyroid gland;* the absence of iodine in the diet causes goiter. The proper functioning of the capillary blood vessels depends upon magnesium. The exact use of the other minerals is unknown, but their presence in the body of a healthy person indicates that they are an essential part of a balanced diet (page 628).

The mineral salts that contain these eleven elements are found chiefly in green leafy vegetables, most fruits, raw oysters, egg yolks, whole milk, and whole grains. Meat is lacking in mineral salts unless it is consumed as flesh eating animals consume it. These animals, in addition to eating the raw flesh, lap the blood and eat parts of bone tissue.

Are poisons ever found on fruits and leafy green vegetables? In order to protect growing plants from the ravages of insect enemies, growers spray the leaves with arsenate of lead or other poisons. Arsenate of lead is a poison not only deadly to insects but also to people. During the growing season the leaves and fruits of plants may receive such a thick coating of poison that some of it may still be on the fruit or leaves of vegetables when they reach the consumer. In order to be certain that no poison remains, all raw fruits and leafy vegetables should be washed thoroughly before they are eaten and also before they are cooked. Of course the same result may be obtained by peeling fruits or vegetables, but, because the skins of most fruits and vegetables contain valuable food materials, it is preferable to wash them.

PROBLEM: WHY ARE VITAMINS NECESSARY TO BUILD A HEALTHY BODY?

What are protective foods? As a result of experiments upon animals, milk and leafy vegetables have been named "protective foods." These foods contain the minerals essential to health. In addition they contain substances called *vitamins*. Very little is known of the composition of vitamins, and chiefly for that reason they are named by letters: vitamin A, B, C, D, E, and G. An animal cannot live and reproduce itself on a diet of carbohydrates, proteins, fats, and mineral salts and nothing more. Its diet must also contain vitamins (Fig. 361). Milk, leafy vegetables, and fruits seem to be the chief sources of vitamins, although there are others.

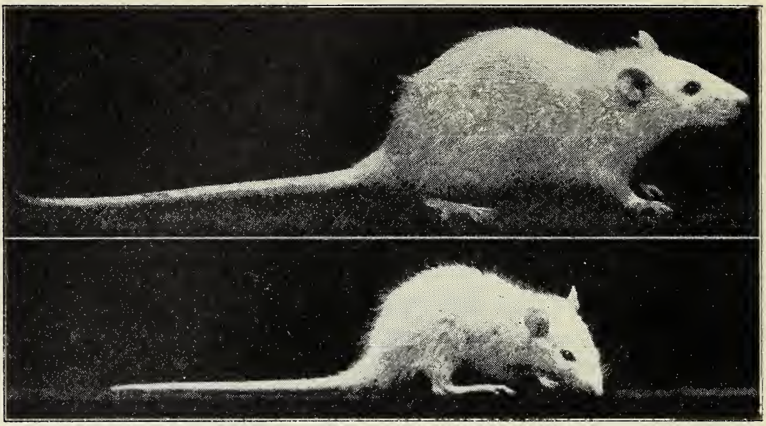


Courtesy College of Agri., Univ. of Missouri

FIG. 361. Photograph of a rabbit 125 days old, paralyzed and helpless. Its condition is due to a diet deficient in vitamins.

Where do vitamins come from? It is believed by scientists who have carried on recent experiments in foods that vitamins are manufactured by the leaves of green plants. They are found in milk because cows eat green grass, hay, and silage. Butter made in June is generally richer in vitamins than butter made in January. Eggs are more valuable as a food if hens eat foods rich in vitamins. If, however, chickens and cows are fed on foods lacking in vitamins, the eggs and milk also will be lacking in vitamins.

Vitamin A. Vitamin A is sometimes called *fat-soluble* A. However, vitamin A is not found to any great extent in any fat, except the fat in whole milk, in the yolk of eggs, and in cod liver oil. It is not a part of olive oil, cottonseed oil, peanut oil, cereals and seeds, except yellow corn. It is present in the green leaves of alfalfa, and clover, and also in carrots, squash, sweet potatoes, and tomatoes. Vitamin A is not destroyed by the common household methods of cooking. The amount of this vitamin in the fat in



Courtesy U. S. Dept. of Agriculture

FIG. 362. The diet of these two rats was the same except that the diet of the one below lacked vitamin B. When 64 days old, the one above weighed more than four times as much as the other.

whole milk and yolk of eggs depends upon the amount and kinds of leafy vegetables fed to the animals which produce these foods. In winter farmers sometimes "sprout" oats to provide vitamins for their chickens. Will this affect the food value of the eggs?

Codfish obtain vitamins from algae, which grow in the sea. Other minute plants found in the sea seem to have the ability to produce this vitamin; these are eaten by tiny marine animals and these in turn by cod. The cod stores large amounts of vitamin A in its liver. Cod liver oil varies in the amount of vitamin content, but the best grades contain fifty times as much vitamin A as cream does.

Liver, especially calves' liver, is rich in vitamin A, and it also contains vitamins B and C. Liver, too, is valuable as a source of protein.

Lack of vitamin A in our diet causes stunted growth, lowered body resistance to disease, eye infection, sinus troubles, and lung weaknesses. It is thought that vitamin A is necessary for the proper growth and development of children.

Vitamin B. Among the foods containing vitamin B (Fig. 360) are certain varieties of beans, especially the navy bean;

either fresh or canned peas; tomatoes; brown rice; pineapple; orange juice; lettuce; celery; egg yolk, and such organs of animals as the brain, kidneys, and liver. Common household methods of cooking do not seem to destroy vitamin B.

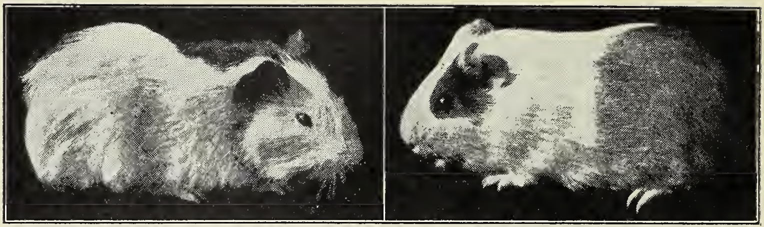
When the United States Government took over the control of the Philippine Islands at the close of the Spanish-American War, it found wretched conditions in certain prisons. In spite of the effort to improve health conditions, a much dreaded nerve disease called beri-beri continued to break out. The diet of the prisoners consisted chiefly of rice from which the brown hull had been removed, i.e. polished rice. Finally, scientists sent to the islands to study health conditions in the prisons served the prisoners rice that was not polished. An almost immediate improvement was noticed and finally the disease was stamped out. From this do you think that bran and other parts of the hull of rice contain a necessary vitamin?

Beri-beri has been common in parts of South America where the diet of laborers consisted largely of meat and cereals. Cases of beri-beri developed among the crew of the Seeadler, a German raider. After it was wrecked during the World War the sailors afloat in an open boat were about to commit suicide because of the discomforts of the disease, when they came to a small island where bananas and other tropical fruits were growing. The captain reports that they experienced almost immediate relief after they had eaten these fruits. Do you think fruits contain the vitamin that prevents beri-beri?

Vitamin B seems necessary for the proper functioning of the nervous system, because a lack of vitamin B in the diet causes disorders in the nervous system and in extreme cases the disease beri-beri, and sometimes death.

Vitamin C. Foods rich in vitamin C are fresh apples, bananas, raw cabbage, grapefruit, lemon juice, lettuce, orange juice, pineapple, white potato, fresh strawberries, and tomatoes. This vitamin has been considered the preventive of the disease, scurvy (Fig. 363).

An experiment in the Serbian army proved that lemon juice and slightly cooked sprouted beans were very effective in curing



Courtesy U. S. Dept. of Agriculture

FIG. 363. Note the crouched position, rough fur, and lack of vigor shown by the guinea pig at the left, due to lack of vitamin C in its diet. These symptoms correspond to those of scurvy in a human being.

cases of scurvy. Prolonged cooking of vegetables and fruits destroys vitamin C.

Nowadays most children are given milk which has been either boiled or pasteurized. These processes destroy vitamin C and children fed exclusively on such milk may develop scurvy. The orange juice or tomato juice added to the diet of children fed on boiled or pasteurized milk will furnish vitamin C and thus prevent scurvy.

Vitamin D. This vitamin, like vitamin A, is soluble in fat. Lack of vitamin D makes children susceptible to rickets.

One of the signs of rickets is an extreme weakness of the bones; the leg bones, for example, may not grow straight because they are not strong enough to support the weight of the body. The bones at the front of the forehead often become much enlarged. This disease may also cause curvature of the spine and may also result in a malformation of the bones of the chest.

Vitamin D assists the bones to utilize the mineral matter which the blood obtains from food. It is found in butter, yolk of eggs, cod liver oil and oils obtained from other fish and in cocoanut oil.

Sunshine and vitamin D. The part that sunshine plays in building and maintaining a healthy body cannot be overestimated. Recent experiments prove that calcium is an element very much needed in the growth of teeth and bones. It can be used by body cells only in the presence of vitamin D or sunshine. Children and adults should be in the sunshine as much as possible. During the winter the most satisfactory substitute for sunshine is cod liver oil.

The examination of several hundred scantily clad children in the tropics showed absolutely no defects in bones or teeth which could be traced to faulty assimilation of calcium. The doctors who made this examination believe this condition of the bones and teeth to be the result of an outdoor life in sunshine. The almost perfect teeth and bones of children and adults in the arctic region is due, doctors believe, to a diet rich in vitamin D. Eskimos eat the bones of animals, which are rich in calcium and furnish the necessary vitamin D for the assimilation of calcium.

Recently, leading electric manufacturing companies have perfected lamps whose light is a somewhat satisfactory substitute for sunshine. Care should be taken in choosing such a lamp, since there are many whose value is doubtful and others which may cause bodily injury.

A word of caution is needed regarding body exposure to sunlight. Your own experiences may have shown that if parts of the body are exposed long enough to direct sunlight, a painful sunburn results. Instead of being helpful to the body, such a sunburn is positively harmful. It is wise to expose the body to sunlight for short intervals until the skin is well tanned. Longer periods of exposure then will not be harmful.

Just as it is possible to expose the body to too much sunlight, so it is possible to overeat vitamins in concentrated form. It is wiser to choose a variety of foods which contain the needed vitamins in sufficient amounts.

Vitamin E. Dr. Herbert Evans, University of California, in experiments with rats found that they could be reared on various food mixtures containing proteins, carbohydrates, fats, salts, and vitamins A and B. These animals had every appearance of health and grew well but eventually they became unable to reproduce. The experiment showed that the ability to reproduce could be regained by the rats if they ate foods containing vitamin E. Sources of this vitamin are lettuce, alfalfa, peas, wheat embryo, and lean meat. It has also been found in oats and corn. When dried, lettuce, alfalfa, and peas retain vitamin E.

Vitamin G. Vitamin G is found in lean beef, milk, and yeast. Its chief use to the body is to prevent pellagra. This disease was first noticed in the United States in 1908. It increased rapidly until in 1917–1918 200,000 cases were reported. Most of these were in the southern part of the United States, although a few cases were reported in Minnesota and Illinois. In 1915, the number of our people who died from pellagra was 10,663.

The disease attacks the digestive tract of both children and adults, causing diarrhea and general physical disability. In many cases mental disability adds to the distress of the patient. When foods containing vitamin G are included in the diet of pellagra patients, their diseased condition improves at once.

The body cannot produce all the vitamins. The best sources of vitamins are from eating a large variety of foods. If the diet is lacking in any vitamin, a person will not enjoy sound health.

Are there other vitamins? When chickens, rats, and rabbits are fed with foods which contain all the known vitamins, they may still become sickly and diseased. Scientists who are studying vitamins believe their diseased condition is brought on by the lack of an unknown vitamin or vitamins.

PROBLEM: WHAT SHOULD WE KNOW ABOUT SOME FAMILIAR FOODS IN PLANNING OUR DAILY DIET?

What is the food value of sugar? Food experiments show that a chocolate caramel, oxidized in the body, produces about 100 calories. The same amount of energy may be furnished by a thick slice of whole wheat bread, or by two eggs, or by a tablespoon of butter. Do you think the caramel has the same food value because it produces the same number of calories?

Three common kinds of sugar are: sucrose, maltose, and lactose. *Sucrose* is the sugar found in sugar cane and sugar beets. Highly purified sucrose is the granulated sugar which we use in our homes. *Maltose* is the sugar produced by the germination of barley and other grains. *Lactose*, as you know, is the sugar in milk. Cane and beet sugar (sucrose) are digested and absorbed by the blood much more quickly than either lactose or maltose. Since mineral salts and vitamins are not present in pure sugar, large quantities of it may be harmful to the body because they take the place of other foods essential to a balanced diet. Also, the quantity of sugar in the blood may increase above the normal amount and may tend to bring on the disease, diabetes. Explain why eating a great deal of candy may impair health.

Milk, the perfect food. Milk has often been called the perfect food. Study Figure 364. Can you find any of the essential kinds of food not contained in milk? How many of the vitamins does milk provide? As milk is rich in calcium, it is essential to the diet of children. Why? One quart of milk should be consumed daily by every growing child.

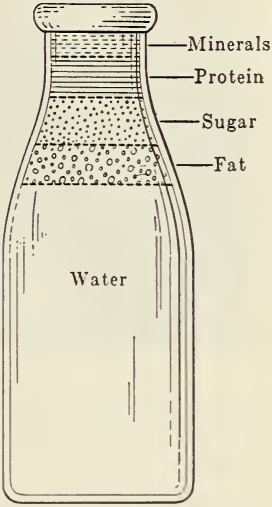
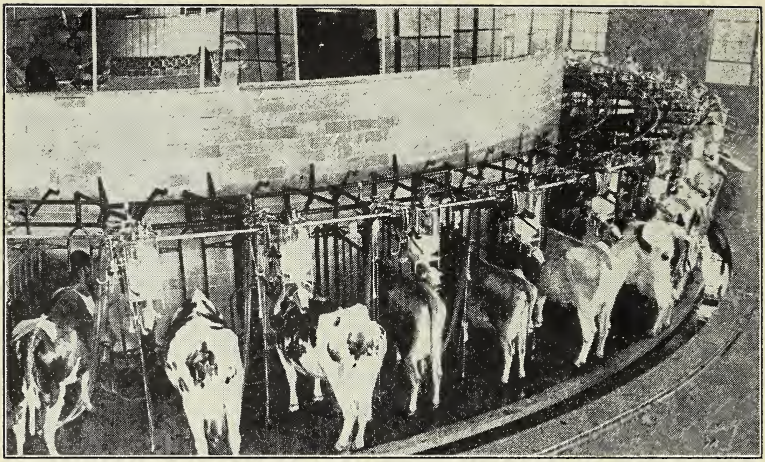


FIG. 364. Observe that milk provides four essentials of a well balanced diet: sugar, protein, fat, and minerals. It also contains vitamins A and D.

How milk is handled. Since milk sours quickly if it is not kept cool and away from dirt and other materials which might contaminate it, great care must be taken to insure sanitary conditions wherever milk is handled (Fig. 365). What methods of handling milk help to keep it in condition fit for food? Milk is a food not only for humans and certain animals but also for disease germs. This means that we must protect milk from the germs which would render it unfit for use.

Enough milk is used each year by the people of the United States to make a lake on which all the navies of the world could be floated. To produce and handle all of this milk you can well understand that there must be a vast army of people who raise and care for cows and collect, transport, and distribute milk. Figure 75 (page 119) shows one method of transporting milk.

What is pasteurization? In order to be sure that the large quantities of fresh milk needed in cities do not contain harmful bacteria, the distributors of milk *pasteurize* it. To pasteurize milk, it is heated to a temperature of 140° F. to 155° F. and kept at



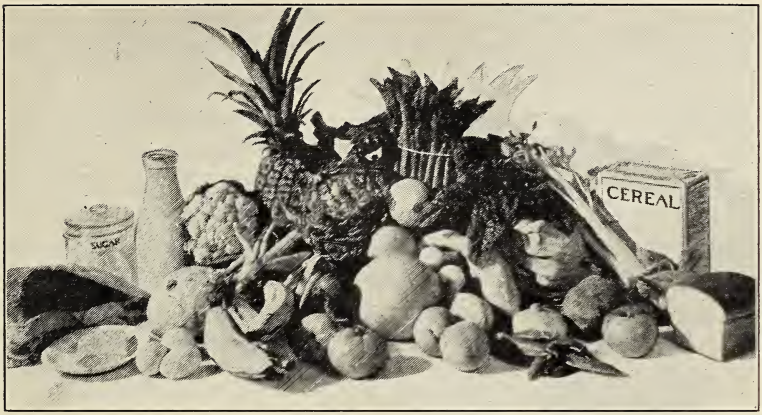
Courtesy Walker-Gordon Co.

FIG. 365. A rotating platform with apparatus that washes, dries, and milks fifty cows in the twelve and a half minutes in which the platform makes one revolution.

that temperature for about fifteen minutes to kill harmful and other bacteria. The milk is then cooled and kept cool until it is delivered to the customer. Louis Pasteur, the great French scientist, devised this method of making milk safe to use.

Pasteurization not only kills bacteria in milk, but it also destroys vitamin C. Why is tomato or orange juice given to a child that is fed with pasteurized milk?

What is certified milk? When raw milk (unpasteurized) is to be used for food, great care must be taken to keep it free from harmful bacteria. To accomplish this, milk producers maintain a laboratory and a staff of trained experts to produce *certified milk*, that is, raw milk which the producer certifies is pure and wholesome. The producer of certified milk must keep his cows in clean barns and in a healthy condition. All persons who handle the milk must also be clean and healthy. All milking machines, if used, must be clean also. Even after all of this care is taken, the milk is tested by a bacteriologist and chemist to be sure that it is of standard quality and free from disease and any other harmful germs.



Courtesy U. S. Bureau of Home Economics

FIG. 366. Name as many of the foods shown here as you can and tell what food essentials each one provides.

Would you expect certified milk to be more expensive than pasteurized milk? Why? What are the advantages of certified milk?

Meat. Not only is meat one of our chief sources of proteins, but other foods served with it taste better than they do when served alone.

To secure from fruits and vegetables the protein needed by the body, it would be necessary to eat large quantities of them. For example, we would have to eat fifty pounds of apples to secure the protein needed by the body in one day. This amount of fruit would provide more sugar than is needed. Why is a diet made up of a great many kinds of food (Fig. 366) more healthful than one made up of just one kind of food.

Potatoes. One of our main sources of starch is potatoes. The layer of active cells just beneath the skin of a potato contains mineral matter and vitamins. Why does peeling a potato lessen its food value? Do you eat the skin of baked potatoes? Is this a healthful practice?

Bread. Another source of starch is bread. Whole wheat bread, bread made from the entire wheat grain (Fig. 367) is particularly valuable as a food. A is the bran or outer part of the wheat grain that contains calcium, phosphorus, iron, proteins, and vitamins. B is the white inner part used to make white flour; C is the germ or living part of the grain, rich in oil and protein.

Which of these food materials are lacking in white bread? Which kind of bread is more healthful? Why?

When should we drink water? Whether or not we should drink water with our meals is a much discussed question. Specialists in foods and diets say it is all right to do so. However, the water should not be ice cold. If drunk at a temperature of 60° F. and not mixed with food in the mouth, water taken at meals aids digestion. Most persons should drink from six to eight glasses of water every day.

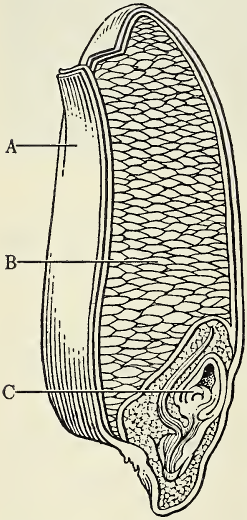


Fig. 367. Sketch of a magnified grain of wheat.

During the night when the body has been in a horizontal position, a small amount of bile and other fluids flow back into the stomach from the small intestine. A morning glass of water tends to wash these fluids from the stomach and to stimulate the flow of gastric juice, thus preparing the stomach for its part in the digestion of food. Similarly, a glass of water before any meal will stimulate the flow of digestive juices. Digested food is absorbed into the blood stream more rapidly if diluted with water. On the other hand, water should never be used to wash food from the mouth into the stomach. Unless food is properly chewed, the saliva is prevented from doing its part in digestion.

Why do we cook food? Proper methods of cooking food change it into forms more easily digested by the body. You might think of cooking as the first step in digestion.

(1) Cooking softens and breaks open the cell walls of plant and animal tissues, thus releasing the proteins, fats, and carbohydrates within the cell.

(2) Cooking breaks up starch grains, thereby making them more easily digested.

(3) Cooking makes certain foods more palatable, thus adding to the pleasure of eating. Attractive looking foods stimulate the flow of digestive juices.

(4) Cooking foods kills bacteria. Why is this desirable? Cooked food is more easily kept than raw foods. Why?

(5) Cooking may destroy vitamins. Why, then, should food be cooked no longer than is necessary?

(6) Cooking frees the juices that contain much of the mineral salts present in a food. Why should we use such juices for food?

Table I. Vitamins Needed to Build a Healthy Body

	Necessary for	*Best sources among foods*
Vitamin A	Growth Prevention of certain eye disorders Resistance to infection Steady nerves	Halibut liver oil Cod liver oil, Butter, Cream Egg yolk, Whole milk Tomatoes, Liver
Vitamin B	Growth Appetite Proper digestion Steady nerves Prevention of beriberi	Yeast, Egg yolk Whole grain cereals Whole milk, Peas Tomatoes, Spinach Beans, Asparagus Carrots, Liver
Vitamin C	Prevention of scurvy Good teeth Proper condition of blood vessels Growth and vitality Strong bones	Oranges, Pineapples Lemons, Grapefruit Strawberries, Peas Tomatoes, Raw cabbage Greens
Vitamin D	Strong bones Good teeth Prevention of rickets	Cod liver oil Halibut liver oil Egg yolk Irradiated milk
Vitamin E	Prevention of sterility	Whole grain cereals Vegetables
Vitamin G	Growth Proper appetite Prevention of pellagra	Yeast, Liver Carrots Kidney, Beef Wheat germ, Spinach Egg, Milk, Prunes

Courtesy H. J. Heinz Co.

Table II. Principal Minerals Needed to Build a Healthy Body

	Necessary for	*Best sources among foods*
Calcium	Strong bones Good teeth Prevention of rickets Steady nerves	Milk, Cheese Egg yolk, Celery Spinach, Beans Cauliflower, Nuts
Phosphorus	Strong bones Good teeth Building of body tissues Prevention of rickets	Egg yolk, Cheese Whole grain cereals Peas, Beans Carrots, Spinach Peanuts, Milk Chocolate, Liver
Iron	Blood-making Cell-building	Liver, Oysters Lean meat, Egg yolk Whole grain cereals Prunes, Apricots Asparagus, Lettuce
Copper	Utilization of iron by blood	Liver, Shrimps Oysters, Poultry Nuts, Whole grains Leafy vegetables, Peas
Iodine	Proper functioning of thyroid gland	Oysters, Shrimps Clams, Sea fish Iodized salt

Courtesy H. J. Heinz Co.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

appetite
balanced diet
beri-beri
calorie
carbohydrate
certify
fat
glycogen
maltose
mineral matter
lactose
pasteurization
pellagra
protein
rickets
scurvy
starch
sucrose
sugar
thyroid gland
vitamin

Write the number of each item on your paper and after it the word that completes the statement.

1. Fats and carbohydrates furnish ________ for the body.
2. The ________ are used for body growth and repair of tissues.

3. Milk contains sugar known as ________.

4. The food substances which are body regulators are the ________.

5. Green leafy vegetables and milk are called the ________ foods.

6. Vitamin ________ provides for growth and resistance to disease.

7. The disease, ________, is caused by a lack of vitamin B.

8. Lack of vitamin ________ causes sterility.

9. Sunshine is a good substitute for vitamin ________.

10. Fruits are the best source of vitamin ________.

11. Vitamin ________ is necessary for the proper growth of bones and teeth.

12. The best source of the element calcium in food is ________.

13. The number of different vitamins that have been discovered up to the present time is ________.

14. The unit used to measure food value is the ________.

15. All kinds of proteins contain the elements, ____, ____, ____, and ____; certain kinds of proteins contain these four elements and also the elements, ____, and ____.

Which of these statements are true? If any are false, re-state them in correct form.

16. The metal, copper, is an essential element in the diet.

17. A careful selection of food is not essential to sound health.

18. The active chlorophyll cells of green plants are necessary for the health of animals.

19. Besides carbon, hydrogen, and oxygen, proteins always contain the element chlorine.

20. Proteins supply the body with energy.

21. Fats and carbohydrates are called body regulators.

22. A pleasant disposition and optimistic point of view is dependent in part upon vitamin C in the diet.

23. Vitamin E in the diet promotes growth and builds up bodily resistance.

24. Only children contract the bone disease called rickets.

25. Vitamin C and sunlight have the same effect upon the body.

26. Vitamins should never be eaten in concentrated form.

27. Cooking destroys the vitamins in foods.

28. Sunburn is beneficial to the body.

29. Pasteurization destroys bacteria and vitamins in milk.

CHAPTER XXXI

HOW DO THE ORGANS OF THE BODY COOPERATE IN MAINTAINING HEALTH?

Do you know:

That all food before it can be used by the body must be changed into a solution? That you do not have all of your teeth until about the age of eighteen? That sound teeth depend in large part upon the kind of food we eat? That the intestines contain millions of bacteria? That the blood carries food and oxygen to the cells? That the white corpuscles devour disease germs? That oxygen causes the blood to be red?

That the circulation of blood was not discovered until a little more than three hundred years ago? Why one lung is larger than the other? That in breathing, air is forced into the lungs by air pressure? That some glands (organs) secrete substances that stimulate other organs of the body? That the size of an abnormally large person may be due to the activity of a small gland? That the nervous system is composed of cells?

Problem: How Is Food Changed into Usable Body Building Material?

Do surroundings affect digestion? As you know food must be changed into liquid form before the body can make use of it. The process involved in changing foods into liquid form is called *digestion*. Many factors aid or hinder digestion. If possible meals should be eaten leisurely in a quiet, attractive place. In a busy restaurant, surrounded by hustling waiters and amid shrill noises and the clatter of dishes, a person is apt to eat rapidly and to swallow his food without chewing it enough.

When a person is angry, fearful, worried, or in an argumentative mood, he is not apt to chew his food properly; the muscles of his stomach and intestines do not function normally; and the digestive juices are not secreted at the usual rate.

Attractive and well-cooked food is more easily digested than unattractive food. The senses of taste and smell are essential to normal digestion. An appetizing odor stimulates the flow of the digestive juices, or as we say, "makes our mouths water."

How is food changed in the mouth? The *teeth* perform the first step in digestion. They are so constructed that we are able to bite off, tear, and grind food. If you wished to dissolve a large lump of ice, would breaking it up into smaller pieces hasten the process? Do you think the tearing up of food by the teeth aids in digestion? Can you suggest another reason why food must be broken up into small bits by the teeth?

Have you ever played the game in which the first one to eat and swallow a dry cracker wins? Before you can swallow the cracker, what happens to it? The fluid with which the cracker is mixed as you chew it is called *saliva.* It is secreted by glands in the mouth. A *gland* is an organ which secretes a fluid which is either used by the body or expelled from it. Not only does saliva help you to swallow dry food, but it also acts chemically on the starch in foods. It starts the process of turning starches into liquid form.

Explain why slow and thorough chewing of all foods aids in digestion.

How should we care for our teeth? You have seen how teeth play a part in the digestion of food. You do not need to be told, then, why you must take care of them, i.e., both the first and second set. The first set, consisting of twenty teeth, begins to appear when a child is about six months old. The second, that is, the permanent set, consists of thirty-two teeth, sixteen in each jaw. The first permanent teeth to appear are the first molars, which come about the sixth year. During the seventh year, the two central incisors appear; during the eighth, the lateral incisors. The bicuspids appear about the ninth or tenth year; the canines at eleven or twelve; the second pair of molars at twelve or thirteen; and the third molars, sometimes called wisdom teeth, appear at the age of eighteen or later.

By using a mirror, locate each kind of tooth. How many teeth do you have? Have your third molars yet appeared?

The first way in which you should take care of your teeth is by eating food which contains tooth-building material. Each tooth is made up of a hard substance composed chiefly of calcium phosphate. The food that best supplies calcium phosphate is milk; however, it is also found in other foods. If your meals are of the kind indicated in Chapter XXX, your diet will supply you with the materials for building sound teeth. The food of children should be so chosen as to furnish plenty of tooth-building materials.

Exercise is necessary to keep the teeth strong and the gums tough. When you chew crusts and raw fibrous foods such as celery, lettuce, cabbage, radishes, and the like, more blood is sent to the teeth than when you eat soft or cooked foods. This blood carries with it tooth-building materials and oxygen; it also removes waste. Vigorous brushing of the teeth will also bring more blood to the gums and thus help to nourish the teeth.

Teeth must be cleaned regularly if they are to be kept in a healthful condition. They should be brushed at least twice a day with a preparation that contains a mild alkali such as milk of magnesia or a mixture of soda and salt. The next time you go to a dentist, ask him to tell you how to take proper care of your teeth. Why should you go to a dentist regularly every three to six months?

If food particles are permitted to remain on or between the teeth, all conditions for rapid growth of bacteria are present (food, warmth, and moisture) and may produce tooth decay. As poisons from decayed teeth enter the blood stream, they are carried to all parts of the body and may cause serious trouble.

How is food swallowed? After food has been chewed and mixed with saliva, it is rolled up by the tongue into a smooth, moist mass. From the mouth, food passes through the opening into the *gullet* (esophagus) and on to the stomach. As soon as food leaves the mouth it passes beyond our control. From then on it is subject to processes that are automatic.

The walls of the gullet contain a series of circular muscles, that look like rings. These muscles, by contracting one after the other, force food along the gullet. If you have ever watched a horse drink, you may have noticed the wave-like movement along its neck after each swallow of water. Explain. This wave-like movement can also be seen in a cow's neck as she swallows when she is chewing her cud.

How is food changed in the stomach? The stomach is a pear-shaped organ; when filled it holds from three to five pints. When food leaves the gullet and enters at one end of the stomach, a wave-like movement begins near the middle of the stomach, and passes toward the end where the small intestine is attached. While food is being digested in the stomach, such waves occur about every thirty seconds. The opening that leads from the stomach to the small intestine is called the *pylorus* (Fig. 368).

As the pylorus remains closed while the food is being digested, the successive waves cause the food to be thoroughly mixed with gastric juice. When the pylorus is open, the waves force the food through the pylorus into the small intestine.

Gastric juice contains two substances called enzymes. An *enzyme* is a substance that helps to produce chemical changes in substances in which it is present without undergoing any change itself. The two enzymes in gastric juice are *rennin* and *pepsin*.

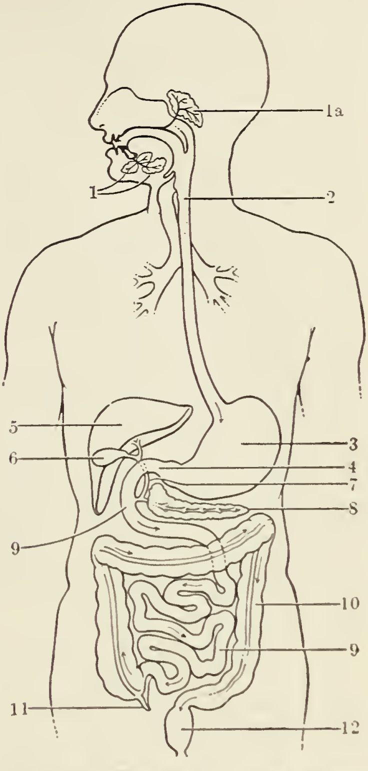


FIG. 368. Diagram of the digestive system: 1 and 1a, salivary glands; 2, gullet; 3, stomach; 4, pylorus; 5, liver; 6, gall bladder; 7, bile duct; 8, pancreas; 9, small intestine; 10, large intestine; 11, appendix; 12, rectum.

Pepsin helps to change proteins from a solid to a liquid form. Moreover pepsin dissolves the connective fibers which hold muscle fibers and fat globules together. As a result the muscle fibers separate one from the other and the fat globules are freed. The digestion of meat which is begun in the stomach is completed in the intestines, chiefly in the smaller. Fat globules although set free in the stomach are digested only in the intestines. Rennin causes milk to curdle. This curdled milk remains in the stomach long enough to permit the juices of the stomach to start the work of digesting the proteins in milk.

How is food changed in the small intestine? When food is ready to leave the stomach, it is in a soft, moist form called *chyme.* The chyme passes through the pylorus into the small intestine, a tube about 20 feet long and about one inch in diameter in an adult. The walls of the small intestine are thin and soft; the inner walls contain a large number of small glands and the outer walls contain muscle cells. Some of the muscles are in the form of rings. The rings contract and produce a wave which begins with the rings nearest the stomach and moves toward the large intestine all the time forcing the material in the small intestine ahead of it. This movement is aided by certain muscles running lengthwise of the small intestine.

Near the beginning of the small intestine, juices, each containing enzymes, enter through a common tube. One of these juices comes from a gland called the *pancreas;* the other from the *liver,* the largest gland in the body. The juice from the pancreas contains: (1) a substance that changes to sugar any starch that was swallowed before the saliva had time to change it into sugar; (2) a substance that changes into simpler compounds proteins that have passed through the stomach without being digested by the pepsin; and (3) a substance that breaks up the fats set free by pepsin in the stomach and changes them into glycerin and fatty acids, both of which are insoluble in water and therefore cannot be absorbed by glands in the cell walls. Here is where the liver comes in. It secretes a fluid called *bile,* which assists in the absorption by the cells of the intestines of glycerin and fatty acids.

What is the purpose of the large intestine? The refuse and whatever foods were not digested in the small intestine pass from it into the large intestine where they stay until the body eliminates them. In the large intestine the digestive juices may continue their action as long as either refuse or food remains. The large intestine contains millions of bacteria. If the refuse is not eliminated from the large intestine regularly, a condition known as constipation results. Many times constipation is accompanied by headache, bad breath, indigestion, loss of appetite and drowsiness.

One of the outstanding faults of the diets of the American people is the lack of foods which prevent constipation. This condition has led to the wide-spread and unwise use of laxatives. Advertisements in newspapers, magazines, and over the radio tell the benefits of this or that laxative. The continued use of any laxative without the advice of a physician is a dangerous practice and should be discontinued. Most cases of constipation can be corrected by proper diet and proper exercise and the habit of a daily bowel evacuation. Some of the ways in which constipation can be avoided are: (1) Lead a regular life as to time for eating, sleeping, working, and elimination of wastes. (2) Eat every day some coarse food, especially leafy vegetables. (3) Include fruit in your diet every day. (4) Drink at least six to eight glasses of water daily. (5) Take daily exercise in the open air if possible. (6) Sleep eight hours daily. (7) Avoid excesses of all kinds.

How is food assimilated? By the time partly digested food reaches the small intestine, some of the digestible food has been changed into liquid form. In the inner lining of the small intestine are countless projections, called *villi*. Through the cell walls of the villi food is absorbed into the blood stream. Compare the action of the villi with that of the root hairs which absorb liquid food from the soil.

The blood stream carries liquid food to cells in all parts of the body. Each cell absorbs food to supply its own needs. This absorption of food by cells is called *assimilation*. The blood, in flowing through the lungs, obtains oxygen which it carries to the body cells. In these cells oxygen and liquid food nourish and re-build the millions of body cells.

PROBLEM: HOW IS FOOD TRANSPORTED TO THE CELLS OF THE BODY?

The blood, the great carrier of the body. Each cell in the body has certain definite needs. It must have (1) food for its own growth and repair, (2) oxygen to change this food into energy, and (3) a means of ridding itself of waste materials. In addition, each cell needs protection against dangerous disease germs. All of these needs are supplied by the blood.

If you looked at a drop of blood under the microscope, you would see small bodies that look like rolls of coins and other bodies that are irregular in shape. The former are *red corpuscles;* the latter *white corpuscles.* The red and white corpuscles are in a clear fluid, the *plasma.* Plasma makes up about two-thirds of the volume of blood and the corpuscles about one-third. The corpuscles are separate from one another in the blood. Under the microscope the red corpuscles are in rolls because they draw together to form a clot. In a cubic millimeter of blood, much less than a drop, there are 5,000,000 red corpuscles.

Red corpuscles. Red corpuscles are round disk-like cells which contain a reddish material called *hemoglobin.* It is the hemoglobin that carries oxygen to the cells and carbon dioxide away. It can take in either oxygen or carbon dioxide. In the presence of both gases, it absorbs the one which is more abundant. In the body cells it gives up oxygen and unites with carbon dioxide; in the cells of the lungs it gives up carbon dioxide and unites with oxygen.

White corpuscles. The white corpuscles are irregular in shape. There are from 5000 to 7000 of them in a drop of blood. In 1883, the great Russian scientist Metchnikoff discovered that white corpuscles have the power to envelop disease germs and digest them. The white corpuscles, then, serve to guard the cells in the body from disease germs. It has also been found that the connective tissue cells and even certain cells of muscles have this power of destroying disease germs but to a lesser degree.

Plasma. *Plasma* is composed largely of water. It carries food in liquid form to cells in all parts of the body. Carbon dioxide and other cell wastes are carried by it through the veins, from which they are eliminated through the lungs, the pores of the skin, and the kidneys.

The heart, a pump faithful through life. The normal action of the heart is so necessary to the health and efficiency of each of us that it should receive careful study. The heart is located in the front of the middle portion of the chest cavity, slightly to the left of the breast bone. What effect do you think this position of the heart might have upon the size of the left lung as compared to the right lung?

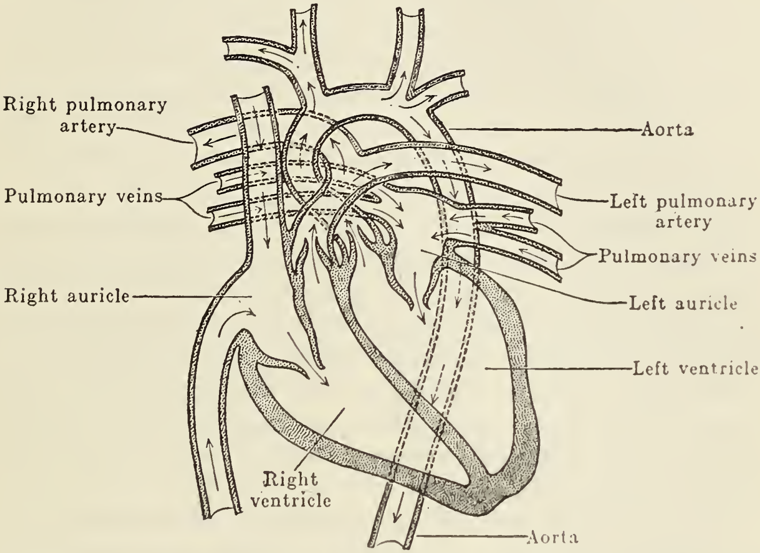


FIG. 369. Diagram showing the chambers of the heart and the larger blood vessels which carry blood to and from the heart.

Experiment 161. To study the structure of the heart. Study a model of a human heart, or secure the heart of a sheep or pig from a meat market, or if it is impossible to obtain a model of a heart, study Figure 369. Hold the heart or model as shown in the figure. The two upper chambers are called *auricles;* the two lower ones *ventricles*. Observe the valves between the auricle and the ventricle on each side of the heart. The valves are so arranged that in a normal heart the blood cannot flow backward.

How does blood clot? If a test tube of blood is left standing for several hours, the blood becomes jelly-like, that is, *clotted.* The test tube can then be inverted without spilling its contents. If the blood remains in the test tube over night, it will shrink and a clear fluid will be noticed along the inside of the tube.

Let us learn what happens in the blood when it clots. If we examine a drop of blood with a high-powered microscope, we can see a fine network of threads in the plasma. These threads are composed of a protein substance called *fibrin.* After the fibrin threads form, they tend to shorten or shrink, pulling the corpuscles together. As this thickening or clotting of the blood helps to close up a wound, it stops the escape of blood from flesh wounds, but not if an artery or large vein is injured because the flow of blood is so rapid that clotting cannot take place.

The circulation of the blood. Let us start with blood in the right auricle (Fig. 369). Here the blood has a bluish color because it has taken in carbon dioxide from the body cells and has given up much of the oxygen (which causes blood to be red) to the body cells. During the contraction of the right auricle, blood is forced through a valve into the right ventricle. The contraction of the right ventricle forces blood through both the right and left pulmonary arteries to both lobes of the lungs where it flows through a fine network of capillaries.

Through the thin walls of the capillaries, carbon dioxide passes from the blood into the air cells of the lungs, and oxygen passes from the air cells into the blood. The oxygen-laden blood then flows from these tiny capillaries into larger and larger veins in the lungs and finally into the pulmonary veins. Through these the purified blood flows back to the left auricle of the heart.

By contracting, the left auricle forces blood through a valve into the left ventricle. As a contraction of the left ventricle must force the blood to the remotest parts of the body, its walls are thick and contain powerful muscles.

The blood leaves the left ventricle through the *aorta,* the largest artery in the body. Not far from the heart, branches lead off from the aorta—one to the right arm, two upward to the head, and one to the left arm. The aorta beyond these branches extends downward and branch again and again into arteries which become smaller and smaller, until they end everywhere in organs in a fine network of capillaries which so completely cover the body that it is almost impossible to insert a pin point into the skin without drawing blood. While blood is passing through the capillaries, food and oxygen are supplied to the body cells to be used for energy, growth, and repair. The capillaries then unite to form tiny veins and these to form larger and larger veins until at last all the blood from the cells of the body is gathered into two large veins through which it flows again to the right auricle and the circulation of blood which we have just described goes on without end during life.

Circulation and health. The discovery of the circulation of the blood was a long step in the development of a sound theory of medicine. Galen (130-200 A.D.) is thought to be the first physiologist. His work is interesting to us because (unlike Aristotle), he drew his conclusions from what he learned by dissecting animals. His theories concerning the valves of the heart, arteries, and veins were corrected later by Italian scientists. The work of these later scientists paved the way for William Harvey. But Harvey did not have a microscope sufficiently powerful to observe clearly how the blood from the arteries made its way through the capillaries to the veins. He said it "percolated" from the arteries to the veins like water seeps through the earth to form springs, not a very faulty conclusion. However he produced experimental evidence to prove that the blood actually circulates and that the muscular action of the heart caused this circulation. Improvements in the microscope by 1660 revealed the fine network of capillaries which we have mentioned before.

Until about two hundred years ago, it was believed that all diseases were caused by impure blood. So, to cure a disease, it was thought wise to withdraw a certain amount of blood. This was done by "bleeding" the patient, i.e. by opening one of the veins of his arm. Today, however, we know that few diseases attack the blood. On the contrary, the blood is considered the stream of life. It carries white corpuscles which serve as "scavengers." If a white corpuscle comes in contact with a germ, it proceeds to wrap itself around the germ and to destroy it. If a disease germ is outside of a blood vessel, the white corpuscle will pass through the capillary walls and proceed to destroy it. So, instead of removing blood from the body, today, in some instances, more blood is actually injected into the veins of a person who has lost a large quantity of blood in a surgical operation or because of a wound or a bursted blood vessel. This operation is called *blood transfusion.* By transfusing blood from a healthy person into the veins of an injured or sick person many lives have been saved.

Blood pressure. When we studied the manufacture of ice we learned that a compression pump is used to keep the freezing agent at a rather constant pressure. The heart may be compared to a compression pump for it keeps the blood in the circulatory system at a certain pressure. With an instrument called a *mercury manometer*, the blood pressure of an individual can be measured, and this serves as an indication of the condition of the individual's health. Have you ever had your blood pressure tested? If not, ask someone who has, to describe the process to you. A person whose blood pressure is higher or lower than the normal for a person of his age should have a thorough physical examination to help determine the cause and means to overcome it.

Problem: How Does Oxygen Get into the Blood?

Air passages. Air enters the body through the mouth and nostrils and from them it passes through the windpipe into the lungs. The windpipe is a tube about three quarters of an inch in diameter and about four inches long. Its walls are strengthened by rings of cartilage. The windpipe divides at its lower end into two branches called the *bronchi.* These divide again and again until the last divisions are numberless tiny air sacs or air cells. These air cells are surrounded by two layers. Between the two layers is a network of thin-walled capillaries. The blood in the capillaries is separated from air in the cells only by the thin walls of the capillaries, and the thin inner walls of the air cells.

The lungs. All these tiny air cells, together with the system of connecting tubes and the capillaries, make up the *lungs.*

These cells, tubes, and blood vessels are held in place as a light, spongy mass by elastic connective tissue, and are covered with a mucous coat. In appearance the lungs are pinkish gray. The right lung is larger than the left one. Can you suggest a reason for this? Each lung is surrounded by an elastic watery membrane connected with another membrane of the same kind which lines the chest cavity. These membranes are called the *pleura*. As the lungs expand and contract in breathing, these two membranes slide over each other with so little friction that we are not aware of the movement. If the pleura become inflamed and dry, pain is caused when we breathe by the friction produced by their movements. This condition of the pleura is known as *pleurisy*. Breathing by human beings and higher animals is a twofold process: drawing air into the lungs, called *inhaling;* and forcing air out of the lungs, called *exhaling*.

Experiment 162. To demonstrate how we breathe. Tie a rubber balloon partly filled with air to one end of a glass tube. Run the other end through a rubber stopper. Fit the stopper into a bell jar with the balloon inside the jar. Glue a piece of leather with a string attached to the center of a sheet of rubber. Tie the rubber securely over the bottom of the jar. When all connections are air-tight, pull the string and observe what happens to the rubber balloon. What happens when the rubber sheet is allowed to return to its former position? Explain.

The breathing process is very much the same as that shown in this experiment. A broad muscle just below the lungs corresponds to the rubber sheet. This muscle is called the *diaphragm*. When you inhale the diaphragm goes down and flattens out, and at the same time certain muscles of the chest contract, pulling the ribs upward and outward, thus enlarging the chest cavity. This action causes a partial vacuum in the air cells of the lungs and air passages, into which air is forced by the pressure of the atmosphere. From the air cells of the lungs oxygen passes through their walls and the walls of the capillaries into the blood; carbon dioxide and water vapor pass from the blood in the capillaries into the air cells of the lungs. When you exhale, the diaphragm rises and the same muscles of the chest relax, letting the ribs spring back, thus decreasing the size of the chest cavity and reducing the volume of air the lungs can hold. The air with the carbon dioxide from the blood and water vapor is thus forced out of the lungs through the air passages.

Hygiene of breathing. As far as possible, the air which reaches your lungs should be free from dust and at body temperature. If you breathe through your nostrils, these two requirements will under normal air conditions be fulfilled. The nostrils lead to an opening above the roof of the mouth, called the *nasal cavity*. The entrance to the nasal cavity is guarded by hairs which strain dust particles from air as it is inhaled. The cavity is lined with mucous membrane. The moisture produced by the membrane also aids in removing dust particles from the air. As this membrane contains many blood vessels, the temperature of the membrane helps to raise or to lower the temperature of the air to about body temperature as it passes through the nasal cavity on its way to the lungs. Air can pass readily through the mouth to the lungs but the mouth is not provided with safeguards which free the air from dust or change its temperature. Should you breathe through your mouth while running in the open air on a cold day, a pain in your chest would likely develop because cold air was inhaled into your lungs. Mouth breathing by children is likely to interfere with the normal development of the upper jaw and injure the appearance of the face.

PROBLEM: WHAT ARE THE CHEMICAL MESSENGERS OF THE BODY?

Something about glands. What glands aid in the digestion of food? List these glands and tell the purpose of the secretion of each. They are not the only glands in the body. Sweat glands gather wastes from the blood and expel them from the body through pores in the skin. Then there are glands without ducts that secrete chemicals which pass directly into the blood stream. These are called *ductless glands*, chief of which are those in the neck (*thyroid*), at the lower front of the brain (*pituitary*), and those attached to the kidneys (*adrenal*).

The chemical messengers. The ductless glands and certain others, like the pancreas and the glands in the lining of the small intestine, secrete chemicals that stimulate other organs. To discover the work of these chemical secretions, they have been studied by observing their effect on the organs of the body. They seem to stimulate the action of organs much as messages from a general stir the activities of the troops. These chemical messengers in the body are called *hormones.*

How do hormones affect the body? When hormones secreted by the pancreas are carried to the liver they cause that organ to store up sugar (glycogen) for future use. The hormones produced by the glands in the small intestine stimulate the pancreas to perform its function.

The thyroid gland produces a hormone that stimulates the growth of the body and the development of the brain. This hormone is sometimes called the iodine-controlling hormone because if a person does not get enough iodine in drinking water and food, the thyroid gland becomes enlarged, resulting in a goiter. Iodine is found in vegetation and in water especially near the sea, in seaweed and in sea foods. Why is goiter less common among people living near the sea than among those living far from it?

Interesting are the hormones secreted by the pituitary gland. This gland is about the size of a cherry and is located back of the eyes. If this gland is larger than normal its hormones may cause a person to grow to the size of a giant. If the gland is under-sized or diseased its hormones may cause a person to be a dwarf.

The adrenal glands produce hormones that are thought to be messengers that affect organs that may supply the energy needed to furnish the reserve strength or energy needed for an emergency. Under a strong emotion, such as fear or anger, these hormones cause the liver to give up its sugar to the blood to increase activity. A large flow of blood goes to the muscles and the brain. Sight and hearing are alert. Concentration is so intense that animals seem to be insensible to pain. Under strong emotion elderly people, seemingly feeble, have been known to move with incredible speed.

Other ductless glands produce hormones which regulate body structure and growth.

PROBLEM: WHAT DIRECTS THE PROCESS OF BUILDING AND MAINTAINING THE BODY?

In a complex organism like the human body a centralized influence is needed to direct and control the activities of its different parts. This work is done by the brain, spinal cord, and nerves. Taken together they make up the *nervous system.*

You have experienced the working of your nervous system all of your life. If your hand touches a hot stove, you jerk it away "without thinking." If an automobile horn sounds behind you, you jump. If you put food into your mouth, saliva flows. When something comes dangerously close to your eyes, you wink. You did not make any decision to perform these acts; they took place without conscious effort on your part. Such actions as these are called *reflex actions.*

Perhaps you have learned to play the violin or the piano. Or you may be a baseball pitcher who has learned how to pitch a fast ball and a curve. If you are, then during years of practice you have learned the proper position of your fingers on the ball and the body movements needed to pitch a ball as you may desire. In so doing you have formed *habits*, that is, *nerve patterns* in your brain and other parts of your nervous system. To understand how these nerve patterns get started and become more or less fixed, we shall have to learn something about each of the three parts of the nervous system.

The network of nerves. Scattered everywhere through the body is nerve tissue that is made up of cells just as are all other tissues in the body. But *nerve cells* have a structure that makes them quite different from any other cells and which fits them for the special work which they do. A nerve cell, *neurone,* consists of a cell with a nucleus and also fibers which grow out from the center of the cell (Fig. 370). One set of fibers branches irregularly like the twigs of a tree; these are called *dendrites.* The other fibers are long and slender and are called *axons.*

In order to work together, the neurones must be connected in some way. This connection is brought about because the dendrites of one neurone lie close to the dendrites of another neurone.

The branches of two neurones do not actually unite or fuse; they merely lie close to one another. This contiguity of neurones is called a *synapse.*

A *nerve* may consist of a single neurone, or it may be a series of neurones, all leading eventually to either the spinal cord or the brain. The nerves, like the blood vessels, form a network that penetrates into every part of the body.

The spinal cord. Enclosed in the backbone and protected by its bony parts (*vertebrae*) from injury is a large nerve known as the *spinal cord.*

Special problem. Obtain a piece of the backbone of a cow, calf or the like from a meat dealer. Have the backbone split through the middle so that part of the spinal cord may be seen easily. Try to locate the kind of nerves described below.

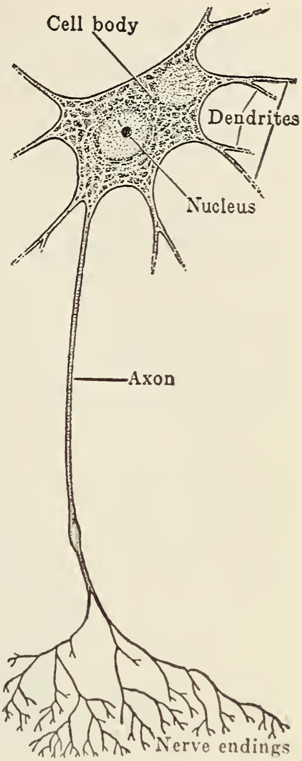


FIG. 370. Diagram of a neurone.

From each side of the spinal cord in man, thirty-one pairs of nerves branch out through openings between the vertebrae. One nerve of each pair consists of nerve fibers that carry sensations from other parts of the body to the spinal cord; for instance, the sensations caused by touching a hot iron. The other nerve of each pair consists of nerve fibers that carry messages from the spinal cord to the muscles, glands, and the like. In a reflex action (Fig. 371), the sensation carried by the first nerve reaches the spinal cord and through the second nerve a command goes back to a muscle or a gland. Both actions take place without involving the brain at all.

Some of the sensations that enter the spinal cord are on their way through the spinal cord to the brain; the brain also sends commands through the spinal cord, to the nerves, and finally to the muscles and glands. So you see that the spinal cord has two functions: (1) it acts as a connecting cord between the brain and the nerve cells in all parts of the body; (2) it contains the nerve centers which control reflexes.

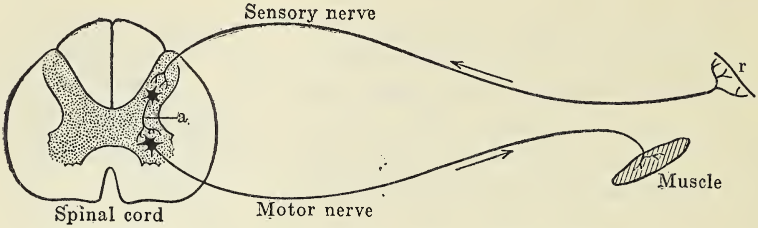


Fig. 371. Trace the path of the reflex from *r*, where the sensation is received, to the muscle which responds.

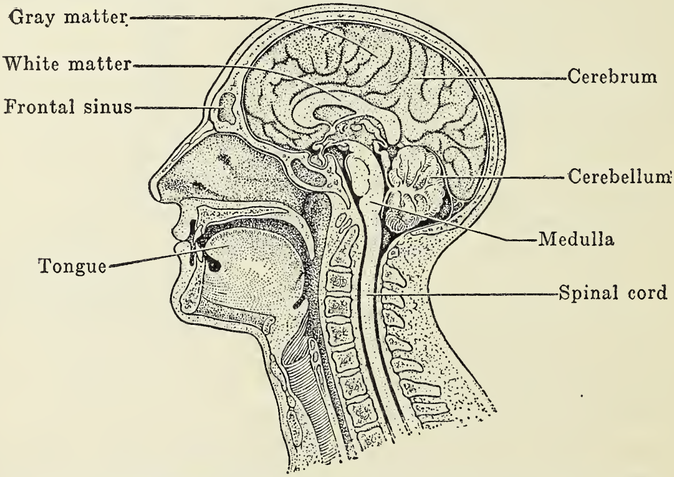


Fig. 372. Cross-section of the head and upper part of the neck.

The brain, the center of all mental life. The main parts of the brain are the *cerebrum*, the *cerebellum*, and the *medulla*. If possible, examine a model of a human brain (Fig. 372). Notice that its outside is made up of gray matter; the inside of white matter. The greater part of the gray matter is made up of many millions of nerve cells; the white matter appears to be made up almost entirely of nerve fibers which spring from the nerve cells in the gray matter.

What are the functions of the medulla? The medulla is situated at the base of the brain and is an enlargement of the end of the spinal cord within the skull. The particular activities which are controlled by the nerve cells of the medulla have been determined by a series of observations, especially of animals in which unusual circumstances have destroyed the functions of the rest of the brain. Such an animal keeps on breathing; its blood vessels continue to expand and contract, and the muscles of its stomach continue their activity. This indicates that the nerve centers which control the movements of the stomach, the beating of the heart, and the breathing of the animal are in the medulla. In general, we might say that the medulla controls the involuntary, reflex activities of the body.

What is the function of the cerebellum? In observations of frogs which possess a cerebellum, medulla, and spinal cord, but not a cerebrum, it has been noted that they can swim and croak, and can eat food that is placed in their mouths. A dog without a cerebrum can walk, and can eat if food is placed in his mouth. Of course, chewing and swallowing are reflexes and hence are controlled in the spinal cord; the medulla controls the stomach and intestines, so the food eaten by such animals is digested. While a dog without a cerebrum can walk around almost like a normal dog, he is blind and deaf; he shows no signs of affection for those who feed him; in fact, he snarls every time he is approached; he does not wag his tail or show any of the signs of pleasure which a normal dog exhibits.

The main function of the cerebellum, however, is that of a coordinating center. Messages which reach it are brought together in such a way that the movements which they produce take place in an orderly, related manner. It is due to this coordinating power of the cerebellum that a person can do several things at the same time—for the muscles of the neck to turn the head while those of the tongue and mouth are concerned with speaking, etc.

What is the function of the cerebrum? The nerve cells in the cerebrum are the real center of thinking, perceiving, willing, and even of consciousness. They are the cells that enable man to invent, plan, hope, and love; write novels and plays; measure the universe and the atom; in fact to study this book. Nothing is too large or too small for them to think about. It is the nerve cells of the cerebrum that make it possible for us to reach a decision and to perform a voluntary act.

PROBLEM: HOW IS A MESSAGE SENT THROUGH THE NERVOUS SYSTEM?

Nerve messages. The sensations that arise in our sense organs of feeling, sight, hearing, odor, and taste send messages through the nervous system called *impulses*. These impulses pass to the brain or to clusters of neurones, called *ganglia*, which are located for the most part near the spinal cord; and impulses from the brain and ganglia pass to the muscles. Those nerves that carry impulses to the ganglia and brain are called *sensory nerves* because they carry sensations of feeling, sight, hearing, smelling, and taste. The nerves that carry impulses from the brain and ganglia to the muscles are called *motor nerves* because they carry the impulses that cause muscles to move (see Fig. 371). Just what constitutes the nerve impulse is not understood by scientists. If you touch a hot iron, the nerve endings from a neurone nearby become excited or stimulated by the heat and send impulses along sensory nerves to a central ganglion. From it a message is sent to the muscles and these immediately withdraw the hand from danger. In the same way other sensations are received by the nervous system and commands sent to the muscles.

Why do we remember? Every sensation, every idea that comes to the millions of nerve cells in the brain, makes some change in the cells, starting what is sometimes referred to as a path through the brain. Every time the same idea moves through the brain the path is made stronger and can be more easily retraced. Some incident—as an explosion, a wreck, or great fire—may make such a deep impression on your nervous system that the smallest details of the incident may remain clear for the remainder of your life. In other words, the striking incident made deep paths or enduring connections between the nerve cells of the brain. There seem to be three principal factors which determine our ability to remember things: (1) the strength or vividness of the original associations, e.g., such as are produced by striking events, or the clarity of the demonstration of a fact; (2) the frequency of the repetition of associated ideas (a poem or a scientific law repeated many times will make deep and often lasting connections between brain cells); (3) the recency of association of ideas, e.g., if your neighbor has just purchased a green automobile, the next green automobile you see will perhaps remind you of your neighbor's.

Are there good as well as bad habits? Everyone knows that the more often an act is done, the easier it is to do again. Also, that as the act is repeated, more direct and better methods of doing it are developed. Every time an impulse passes from a sensory neurone through a central neurone to a motor neurone, the easier it becomes for a similar impulse to cross from one neurone to the next. After a boy has removed his hat repeatedly as a matter of respect in a given situation he does it without thinking when the same situation recurs. Habits are the results of the repetition of response to stimuli until a certain response follows a certain stimulus almost automatically. Or we say, that a habit is the result of the repeated association of a stimulus and response in the brain. These associations in the brain are made much more readily in youth than later, and for this reason habits of study, of work, and of conduct, including the care of your body, should be formed in early life.

Habits and life. Man, however, is more than a bundle of habits. Habits should be our servants, not our masters. As servants they can be made helpful to us but when they become our masters we become slaves. The person who is merely a creature of habits, no matter how good they may be, is a poor person indeed. We should control and use our habits instead of merely yielding ourselves to them. Habit plays an important part in the acquisition of all skills. The highest skills involve the adjustment and coordination of habits to ever changing and novel conditions. True habits may be acquired involuntarily or by discipline and practice.

A SELF-TEST

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

adrenal
aorta
artery
assimilation
auricle
autointoxication
axon
bile
blood transfusion
brain
bronchi
calcium
capillary
cerebellum
cerebrum
chyme
circulation
clot
corpuscle

dendrite
digestion
ductless glands
enzyme
fibrin
gland
gullet
habits
heart
hemoglobin
hormone
impulse
intestine
liver
lungs
medulla
motor nerve
neuron
nervous system

pancreas
pepsin
phosphorus
pituitary
plasma
pleura
pylorus
reflex acts
rennin
respiration
saliva
sensory nerve
spinal cord
synapse
teeth
vein
ventricle
vertebrae
villi

Write the number of each item on your paper and after it the word that completes the statement.

1. The process of changing foods to liquids that pass into the blood stream is known as ________.

2. The digestive fluid secreted in the mouth is ________.

3. Pepsin and rennin are digestive juices secreted by the glands in the ________.

4. The digested food in the stomach is known as ________.

5. The name of the opening from the stomach into the small intestine is the ________.

6. In the process of digestion sugar is changed into ________.

7. Digested food is carried to the body cells by the ________.

8. The color of red corpuscles is due to ________.

9. Pure blood is carried from the heart to the body cells in tubes called ________.

10. The substance which causes the blood to clot is ________.

11. The circulation of the blood was discovered and explained by ________.

12. The human heart has ________ chambers.

13. The blood is forced from the right ventricle to the ________.

14. The organs of respiration are the ________.

15. A nerve cell is known as a ________.

Which of these statements are true? If any are false, re-state them in correct form.

16. Substances that pass from the large intestine into the blood stream are usually beneficial to the body.

17. Bile is secreted by the pancreas.

18. Glycogen is stored in the pancreas.

19. Bile aids in the absorption of digested proteins.

20. The process by which digested foods pass into the blood is known as digestion.

21. White corpuscles destroy disease germs in the body.

22. White corpuscles are found only in the blood.

23. Most people have more good habits than bad.

THOUGHT EXERCISES FOR UNIT XV

Principles of Science

State the principles of science in this unit in sentence form. One of them is: Foods containing starch and sugar furnish the body with energy.

Questions or Problems

1. Why should leafy vegetables be a part of our diet?
2. How may algae growing in the sea affect our diet?
3. Name foods that are rich in more than one kind of vitamin.
4. Why is the calorie used to measure food values?

5. Why is milk a good food?

6. Discuss the origin of the term pasteurization.

7. Why should a large amount of meat not be eaten at one meal?

8. Why is the skin of a healthy white potato valuable for food?

9. How may drinking water with a meal be harmful?

10. Is an argument over a disputed question good conversation during mealtime? Give reasons.

11. Why does a lumberman require more food than a student?

12. What part of digestion is carried on in the mouth? stomach? small intestine?

13. What is meant by blood transfusion?

14. It is said that red corpuscles carry food to the body cells and waste matter away from the cells. Explain how this statement is true.

15. Why is "mouth" breathing harmful?

16. Why are hormones called chemical messengers?

17. Why is tuberculosis referred to as the "white plague"?

18. What organ unifies the work of other organs, thus keeping them acting together?

19. Discuss the following statement: Successful adult life depends largely upon correct habits developed in youth.

20. What is the function of the following parts of the brain: medulla? cerebellum? cerebrum?

21. Leading authorities on health give the following rule for choosing foods: "Eat what you want after you have eaten what you should." Give your reasons for believing that this is sound advice.

Projects and Reports

1. Make a list of several foods that you like that contain sufficient amounts of vitamin A for your dietary needs. Do the same for vitamins B, C, and G.

2. Make a chart showing what digestive processes take place and what digestive juices are secreted in the mouth, stomach, and small intestine.

3. Make a study of food adulteration and report to the class.

4. Make a study of the use of cosmetics, dentifrices, and soap to discover their real value for keeping hair, teeth, and skin in a healthy condition. Report to the class.

5. Make a list of sound health habits that you should have formed or are forming during your high school course.

6. Read the life and achievements of Louis Pasteur.

References for Reading and Study

1. Clendening, Logan, *The Balanced Diet.* D. Appleton-Century Company.

2. Darrow, F. L., *Thinkers and Doers,* Chapter I, Early Man. Silver Burdett Company.

3. Fishbein, Morris, *Your Diet and Your Health.* McGraw-Hill Book Company.

4. Jordan, W. H., *Principles of Human Nutrition.* The Macmillan Company.

5. Kallet, Arthur, and Schlink, F. J., *100,000,000 Guinea Pigs.* Vanguard Press.

6. Kinne and Cooley, *Foods and Health.* The Macmillan Company.

7. Kinyon and Hopkins, *Junior Food and Clothing,* Part I. Benj. H. Sanborn & Company.

8. Broadhurst, Jean, and Lerrigo, Marion Olive, *Health Horizons,* Chapter VIII. Silver Burdett Company.

9. McCollum, E. V., and Becker, J. Ernestine, *Food Nutrition and Health.* The Macmillan Company.

10. Sherman, Henry C., *Chemistry of Food and Nutrition.* The Macmillan Company.

11. Sherman, Henry C., *Food Products.* The Macmillan Company.

12. Turner, C. E., *Physiology and Health,* Chapters IV, V, VI, X, XI, XII. D. C. Heath & Company.

13. Walters, F. M., *Physiology and Hygiene,* Chapters XXIV, XXV, XXVI. D. C. Heath & Company.

14. Williams, Jesse F., *Healthful Living.* The Macmillan Company.

UNIT XVI

HOW CAN YOU KEEP YOUR BODY HEALTHY?

Exploring Nature's Formula for Sound Health

Have you ever had scarlet fever, measles, or diphtheria? If you have, do you know what made you sick? Such diseases as these are caused by very tiny living things known as microbes. They got their name from the Greek word "micro" which means very, very small. In fact, microbes are so small that they can be seen only with a very high-powered microscope. Microbes are found in air, in water, in soil, and even in plants and animals. The fact that we hear so much about microbes that produce disease often leads us to think that all kinds of microbes are harmful. However, this is not true. Many kinds are not only harmless but positively useful. The term "microbes" includes both plants and animals. The plant microbes are called bacteria and the animal microbes protozoa.

Since life cannot be lived fully unless we enjoy sound health, it is very desirable that we protect our bodies from microbes that produce disease. Your body has an outer defense, the skin, which if kept in a sound and healthy condition will prevent harmful microbes from entering the body. However, they may enter through the mouth and nostrils. It is through these passageways that microbes usually enter the body. If they do enter, the blood and various organs of the body cooperate to destroy them and to remove the poisons which they give off. Should the resisting forces of the body be too weak to destroy these dangerous microbes they may destroy your health and happiness. This unit will not only tell you about harmful microbes but also will tell you of nature's formula for sound health: sunlight, pure air, wholesome food, exercise, and sleep.

CHAPTER XXXII

HOW CAN WE PROTECT OUR BODIES FROM DISEASE?

Do you know:

Whether bacteria are plants or animals? What a germ is? What makes fruit juices "spoil" or ferment? Why drying fruits preserves them? What is found in the air besides gases?

Why you should wash your hands clean before meals? What causes a cut in the skin to become sore? That from the point of view of health a coat of tan is desirable?

What is meant by the resistance of the body? Why white corpuscles are so important to the body? That preservatives in canned goods are often harmful? That there are scientific reasons for "swatting the fly"?

PROBLEM: WHAT VERY SMALL PLANTS AND ANIMALS ARE INJURIOUS TO THE BODY?

What are the smallest living plants? Bacteria are the smallest living things known. Figure 373 gives you some idea of the size of these tiny fungous plants. The name bacteria comes from a Greek word meaning little sticks.

Bacteria exist in three general forms (Fig. 374). (*a*) *Cocci* are ball-shaped bacteria which may be found singly, two together, in chains, and in groups. Among the cocci are the bacteria that cause pneumonia and those that form pus (4). (*b*) *Bacilli* are rod-shaped bacteria found singly or in chains. The bacteria that cause tuberculosis (3), diphtheria (4), and typhoid (6) are bacilli. (*c*) *Spirilla*, as the name indicates, are spiral in form. The bacteria that cause certain kinds of fever are spirilla.

A bacterium is a single-celled plant with a fairly distinct cell wall. As it does not contain chlorophyll bodies, it depends upon animals and green plants for food. The bacterium must absorb food through its cell wall, hence its food must be in liquid form. Was it necessary for the food of the amoeba to be in liquid form?

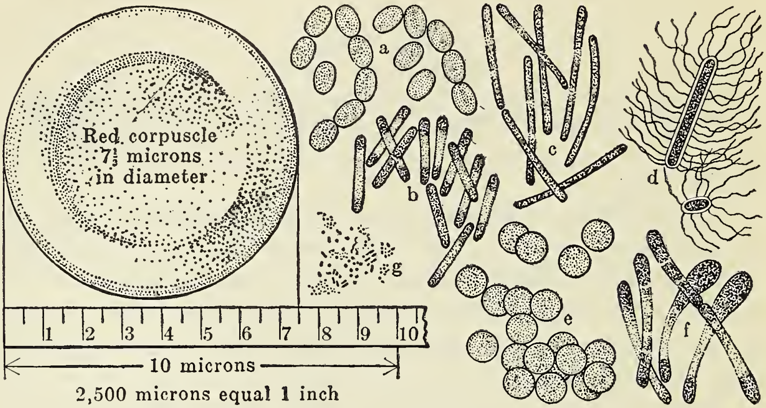


Fig. 373. Several types of bacteria compared in size to a red blood cell: *a*, bacteria that sour milk; *b*, influenza bacteria; *c*, tuberculosis bacteria; *d*, typhoid bacteria; *e*, bacteria found in abscesses; *f*, diphtheria bacteria; *g*, smallpox bacteria, so small that they can pass through a porcelain filter.

Explain. Many bacteria live on food insoluble in water; such a bacterium throws out through its cell wall a liquid containing a substance capable of dissolving solid food material. The dissolved food material is then absorbed into the bacteria and assimilated.

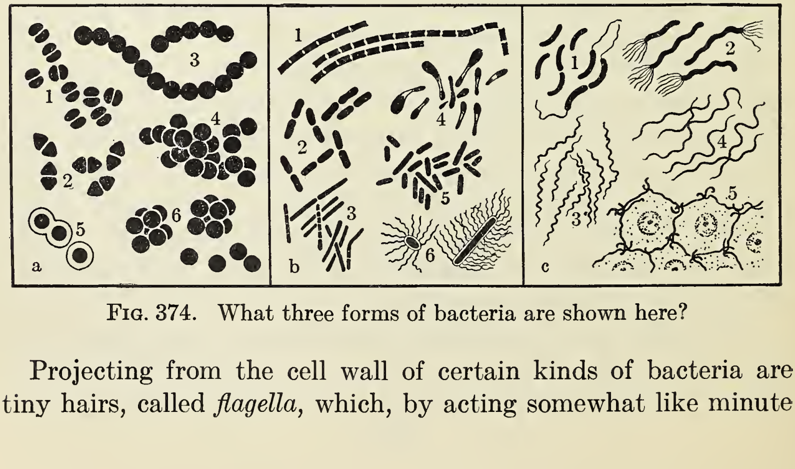


Fig. 374. What three forms of bacteria are shown here?

Projecting from the cell wall of certain kinds of bacteria are tiny hairs, called *flagella*, which, by acting somewhat like minute oars, enable the cell to move about in liquids. Bacteria reproduce by cell division; under favorable conditions they divide as often as once every half hour.

Experiment 163. To grow bacteria. Place six drinking glasses and six glass plates or covers in boiling water; keep them there until you are ready to use them. Then pour a culture medium into each glass and cover it.

1. Remove the cover from one glass, exposing the contents to the air; leave uncovered half an hour; then cover again.
2. Remove the cover from a glass, cough into it, and then replace the cover.
3. Catch a fly and permit it to walk about on the culture medium in another glass. Remove the fly and cover the glass.
4. Remove the cover from a glass, touch the culture medium with the tips of your fingers, and then replace the cover.
5. Remove the cover from a glass, pour a few drops of drinking water upon the culture medium and replace the cover.
6. Keep the other glass covered, taking care that it is not opened at any time. This glass will serve as a control, that is, a check to show how the culture medium acts if nothing is done to it.

Keep the six glasses at a temperature of about 70° F. In three days you may begin to look for results. If bacteria are present in any of the glasses you will be able to see white or yellow spots growing on the culture media. Examine these spots with a magnifying glass, and also place material taken from them under the high power lens of a microscope. Some of the growths on the gelatin may have stems with knobs at the top? What are they?

Tabulate your results. In which glass did the most bacteria grow. The least? What conclusions can you draw about the ways in which bacteria are spread from one place to another?

How rapidly do bacteria multiply? Bacteria multiply (reproduce) by cell division with amazing rapidity. Make a table in your notebook to find out how many bacteria may grow from one bacterium in twelve hours. Remember that at the end of thirty minutes the bacterium has divided to form two bacteria; at the end of the next half hour these two have divided to form four; and so on.

Harmful bacteria. Experiment 163 showed you some of the ways in which bacteria are spread from place to place. Bacteria are almost everywhere; on your hands, clothing, food, and even in the air you breathe. As you know, not all bacteria are harmful. Some of them, however, do cause disease.

Diseases are caused not only by these harmful bacteria but also by protozoa (one-celled animals). We group together as *disease germs* the bacteria and protozoa that, by careful experimentation, are known to cause a diseased condition of the organism in which they live.

Have there always been disease germs? Many persons express the opinion that we are not as healthy and strong as our ancestors were. They claim that in the "good old days" many of the diseases which attack men today were unknown. But investigation reveals that the earliest men were afflicted with diseases. Examination of the bones of prehistoric men shows that they were enlarged, probably by tuberculosis. A study of mummies, reported in the Journal of the American Medical Association, indicates that one was hump-backed. It is believed his backbone was deformed by tuberculosis. The remains of royal families of the past reveal the fact that kings and queens frequently had bad teeth. A great many dwarfs and individuals with deformities due to diseased bones are shown in Egyptian art. All this evidence tends to show that people were afflicted with rickets and tuberculosis of the bone 4000 to 5000 years ago.

Are all bacteria harmful? About nine-tenths of all known bacteria are either harmless or are useful. Milk becomes sour by the action of bacteria (Fig. 375); butter receives its flavor and cheese derives its variety of characteristic tastes, odors, and textures from bacteria and different molds. Fruit juices are changed into vinegar, cabbage becomes sauerkraut, and green corn plants become silage through the work of bacteria. It is even thought that bacteria play a part in the sweet scent of hay. You have already studied how bacteria aid in the separation of linen fibers from the woody fibers of flax and in the softening of skins while leather is being tanned. In the preparation of sponges the jelly-like matter is loosened and removed from the sponge skeleton by the action of bacteria. You have learned, too, of the services performed by these tiny plants in the soil in forming soluble nitrogen compounds from the nitrogen in the air. Why is this of benefit to man?

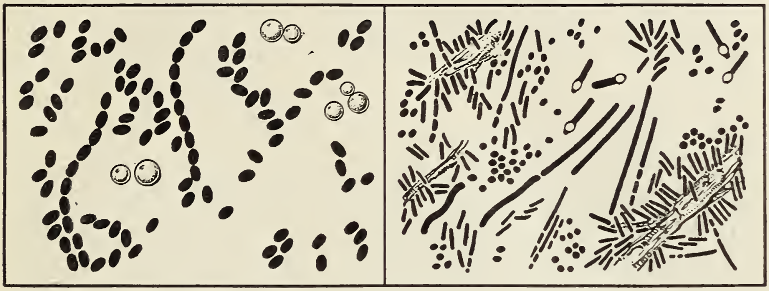


Fig. 375. At the left are shown bacteria that cause milk to sour. The lighter spherical bodies represent fat globules of milk. At the right are fine bits of decaying meat, highly magnified, showing the bacteria that cause its decay. The ones resembling a drumstick are tetanus bacilli.

Bacteria perform another great service by causing the decay of dead matter. Can you imagine what would happen if dead plants and animals did not decay? Bacteria change dead plants and animals into inorganic matter and thereby make it available for the enrichment of soil.

Furthermore, as you know, these tiny servants of ours are made use of in many cities in scientific sewage disposal. Certain kinds of bacteria cause sewage wastes to unite with oxygen from the air to form harmless compounds such as carbon dioxide. Other kinds help to break up the sewage wastes in septic tanks. These bacteria change organic wastes into harmless and inoffensive liquids and gases. Bacteria thus aid us in maintaining sound health.

Problem: How Is the Body Protected from Disease Germs?

Proper disposal of filth. Germs live upon organic matter. Would food or garbage provide food for them? Why should food or garbage be covered? Cities provide for garbage collection and disposal. Explain how garbage is disposed of in your home. You have already learned the need of proper sewage disposal. How is this accomplished in the country? In the city?

What conditions are unfavorable to the growth of germs? Germs, especially bacteria, will grow in temperatures between 40° F. and 100° F. and will multiply most rapidly in temperatures ranging from 70° F. to 80° F. In temperatures below freezing, their activity is suspended, but usually they are not killed. On being thawed out, they will, as a rule, become active again. If germs are placed in boiling water, however, changes brought about in their protoplasm kill them. Does the low temperature in a refrigerator kill bacteria in food?

Bacteria do not grow well in dry places. Their normal development takes place only when twenty-five per cent or more of their food consists of water. Why is milk a substance favorable to the growth of bacteria? Why does drying meat, fruits, or vegetables help to preserve them?

Bacteria do not grow well in acid solutions. Consequently for centuries fruit and meat have been preserved by pickling. You probably know that it is comparatively easy to keep jellies and preserves. They keep well because bacteria do not grow readily in concentrated solutions of sugar. Fish and meat are sometimes salted to preserve them, because bacteria do not grow readily in a salt solution.

How can you prevent the growth of disease germs? From your study you can see that any organic matter, such as scraps of meat, bread, or decaying vegetables, lodged in a moist place, where the temperature is not too high nor too low, is a breeding-place for bacteria and protozoa, including possibly disease germs. The best precaution that can be taken against disease germs is to keep the home, the streets, and all places of occupation clean. Since sunlight is fatal to many kinds of bacteria, it should be let into every room.

How do disease germs get into our bodies? The natural "fortress," protecting our bodies from disease germs, is the skin. If your skin is in a healthy condition, bacteria are not able to get into the body through it. But if there is a cut or break in the skin, bacteria may lodge there and find conditions favorable for growth. Serious inflammation may result and if a wound is not cared for blood poisoning may set in.

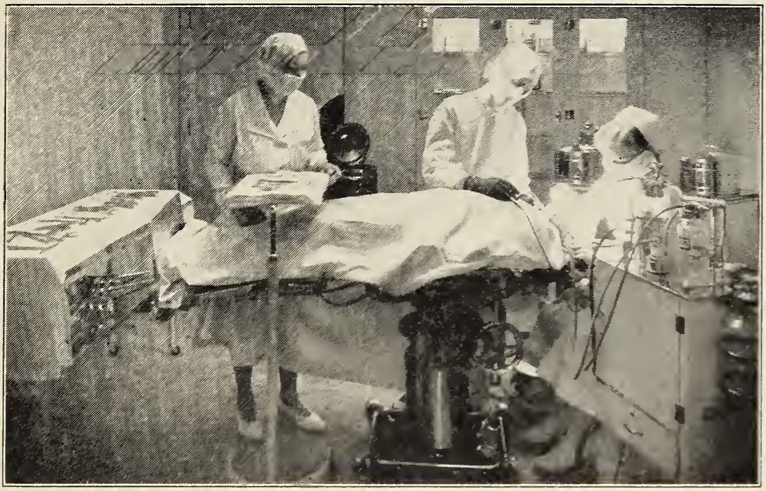


FIG. 376. What precautions are being taken in this operating room to insure cleanliness? Notice that even the doors and closets have been constructed with a minimum area upon which dust may collect.

Disease germs often enter the body through the mouth or nostrils. You have learned that bacteria are always present in the air, in dust, and the like. A person sneezing or coughing sends out into the air a spray of moisture that may contain millions of disease germs. If these germs are breathed into the lungs or lodge in the nostrils or on the lips of another person, he may develop the disease. Thus diseases such as diphtheria, measles, mumps, scarlet fever, smallpox, tuberculosis, and whooping cough may be contracted by persons who do not suspect that they are near anyone who has the disease.

Why should you always cover your nose and mouth when sneezing or coughing? Suggest a reason why schools, theaters, etc., are sometimes closed during disease epidemics.

Why should antiseptics be used? As soon as it became known that germs caused disease, it was natural to begin to treat cuts and broken places on the skin with solutions that would kill any germs lodged there. Such a solution is called an *antiseptic.*

Joseph Lister was the first to use antiseptics, about 1865; he used a solution of carbolic acid in his surgical work. Not only the incision but also the surgeon's hands, his gloves, and the instruments used were treated with a solution of carbolic acid. During an operation even the air of the operating room was sprayed with carbolic acid to kill germs.

It was soon found that although antiseptics destroyed germs, they sometimes interfered with the natural growth of new cells around an incision. Consequently, surgeons in recent years have relied upon perfect cleanliness to keep an incision free from germs. In *aseptic surgery* (Fig. 376), instruments, the surgeon's gloves, and the clothing of all the attendants is carefully sterilized.

You, no doubt, have used tincture of iodine (a two per cent solution of iodine in alcohol), as an antiseptic. What other antiseptics have you used? Without a knowledge of bacteria, people in ancient times learned to protect a wound by means of oil and alcoholic solutions. Explain.

Experiment 164. To show why antiseptics are used. Procure two medium-sized apples with smooth, healthy skins; also one that is decayed (rotten). On each healthy apple break the skin in three widely separated places with the point of a lead pencil or other sharp instrument. Place some of the rotten apple in each of the six holes in the healthy apples. With a medicine dropper carefully fill five of the holes with a drop of the following antiseptics:

Break No. 1—iodine solution
Break No. 2—alcohol (pure)
Break No. 3—mercurochrome
Break No. 4—boric acid
Break No. 5—some other commercial antiseptic
Break No. 6—no antiseptic (control)

Place the apples under a bell jar and observe daily for a week. Which of the antiseptics killed the germs that cause decay? What happened in break No. 6 where no antiseptic was used? Were all of the antiseptics equally good? Do you believe antiseptics should be used on a scratch or cut in your skin? Why?

How can we keep our food free from disease germs? Disease germs may be taken into the body with food. You will readily understand the necessity of handling food with clean hands and of using clean utensils. Make a list of the ways in which you can keep your food free from disease germs.

Do animals carry disease germs? You have learned that flies and mosquitoes carry disease germs. Disease germs may also be carried by dogs, cats, rats, mice, fleas, and other animals. Typhoid, tuberculosis, diphtheria, and other diseases are sometimes spread in this way. Cattle should be examined periodically for tuberculosis. Dogs and cats which you keep for pets should be kept clean and in a healthy condition. Rats, mice, fleas, and lice should be exterminated.

Why should we clean our teeth? If particles of food lodge between the teeth and are not removed, they provide the most favorable conditions for the rapid growth of bacteria. Our mouths are breeding places for disease germs. Explain why neglected teeth may produce bad breath. The bacteria may also act upon the gums and even cause decay of the enamel of the teeth. Careful brushing of teeth after each meal removes these particles of food. Unfortunately, conditions under which people are required to work are such that it is not always possible to brush the teeth after each meal. If this is true, one should be sure to brush the teeth carefully at night to prevent the growth of bacteria in the mouth while asleep. It is better to brush the teeth up and down and in a rotary manner than simply back and forth horizontally. Why?

What is meant by the resistance of the body? The human body in perfect health has the ability either to destroy disease germs or to neutralize the poisons and other products which these tiny enemies produce in the cells of the body. Some people can resist disease better than others. You know that some people do not take cold as easily as others. Some persons are not affected by poisons as readily as others. This tendency of the body to destroy disease germs, or their effects, is known as the *resistance* of the body. Just what makes up this resistance is not clearly understood. It may be some chemical peculiarities of the blood or other fluids in the body, or it may be that the body cells of some people react more quickly to the action of poisons than others. In general, though, the resistance of the body may be taken as an index of the state of health of an individual. The resistance of the body can be kept high by (1) sufficient sleep, (2) plenty of sunshine,

(3) sufficient exercise, (4) proper diet, (5) protection from inclement weather, (6) lack of worry, and (7) freedom from drugs.

Is resistance to disease dependent upon sound health? Experiments have been performed on animals to show the relation between resistance to disease and health. A pigeon in sound health can be inoculated with anthrax germs and not take the disease. But if it is underfed or not fed with the right kinds of food, it will contract the disease readily.

Pasteur experimented with a hen by placing her in cold water until her temperature was below normal. He then inoculated her with anthrax germs. Ordinarily chickens are immune to this disease, but this hen contracted it.

White rats, which are usually immune to anthrax, will take the disease when exhaustion lowers the resistance of the body. What conclusions can be drawn from these experiments? Why do experts on health advise us to keep our bodies in as nearly perfect condition as possible?

What is the effect of food habits on health? The most sensible way to ward off disease is not to indulge in any practice that tends to break down the resistance of the body. If a person continually eats candy between meals, his diet is thrown out of balance, thus diminishing his appetite for body-building foods. An unwise selection of foods may result in disordered digestion and consequently a decrease in body resistance. The use of coffee, tea, and tobacco may hinder proper functioning of the body organs. If a person becomes a victim of alcohol or drug habits, he is destroying the bodily forces which resist disease.

Coffee and tea. A substance which causes an increase in the activity of organs and cells is called a *stimulant.* Coffee and tea are stimulants used by many people. The stimulant in coffee is called caffein; tea contains a stimulant producing similar effects. As neither coffee nor tea has any food value, except for the food value of the sugar and cream that may be used with them, their effect on the body is in no way helpful. Cocoa also contains the same stimulant as the one in tea, but its value as a food outweighs its effects as a stimulant.

Stimulants are especially harmful for growing children. They act somewhat like a whip on a tired horse, keeping tired muscles and brain working when they should be at rest. Probably you know people who do not drink coffee or tea at night because it keeps them awake. Other people become so dependent on the stimulating effects of coffee or tea that they may get a headache or become depressed when deprived of their regular daily amount of these stimulants.

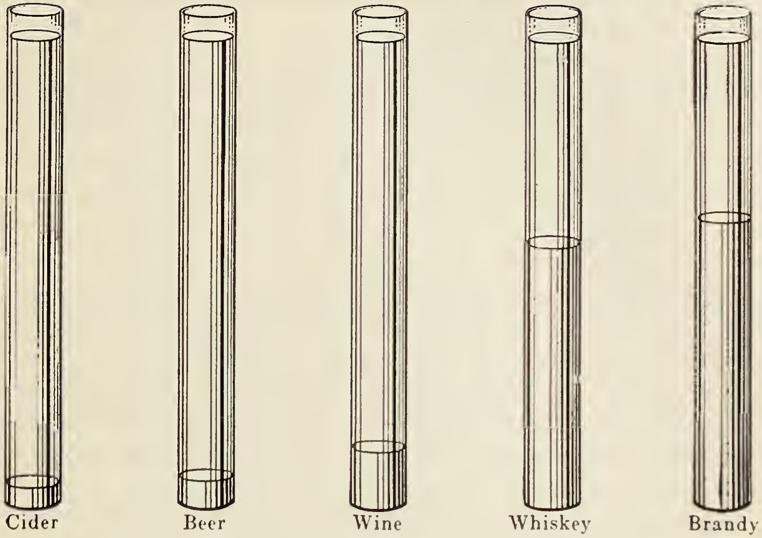


FIG. 377. Relative amounts of alcohol in certain beverages.

Coffee and tea are apt to interfere with the proper development of brain, bone, and muscle. Do you think it is worthwhile to drink coffee and tea? Do you receive any benefits from them? How may they harm you?

For adults, the amount of stimulating drugs contained in a cup of coffee or tea is probably not harmful unless the beverage is made very strong. However, since these beverages have no food value, their use is certainly not beneficial.

Is alcohol harmful? Physicians do not agree on the question of the effects on the human body of alcohol taken in small amounts. Investigations concerning the effects of beverages of alcoholic content on the human system are still in the experimental stage. The effects of beverages of high alcoholic content (Fig. 377) when drunk in large amounts are certainly harmful. A person under the influence of this drug makes silly remarks, is lacking in judgment, and is unable to control the movements of his body. Because of his lack of judgment he is likely to say and do things that he would not otherwise say or do.

The question of the effects on the human body of alcohol taken in small amounts is disputed by physicians. The mind and body seem to be more alert than usual after a small amount of alcohol has been drunk. The action of alcohol in small quantities seems to be chiefly upon the nervous system; the final effect upon nerve-centers is one of depression. The real danger lies in the fact that small amounts of alcohol stimulate a craving that becomes increasingly difficult to satisfy. A person who starts out to drink just small amounts is very apt to drink more and more until he is unable to do without the effects of large amounts of alcohol.

Pure alcohol is labeled a poison by physicians and pharmacists. It is claimed that alcohol lessens the ability of the white corpuscles to destroy disease germs. People who habitually use alcohol to excess often suffer from diseases of the liver and kidneys.

What conclusions can you draw from this discussion of the effects of alcohol? Do you think that the use of beverages containing alcohol is consistent with a desire to have a strong, healthy body?

Is tobacco harmful? The active chemical in tobacco is nicotine, one of the most violent poisons known. Two to three drops of pure nicotine will kill a man. Nicotine does not kill people who smoke because of the small amount taken into the body at one time. When a person smokes for the first time, nicotine usually makes him sick, causing nausea, vomiting, and headache. These are the symptoms of poisoning. If he continues to smoke, his body becomes accustomed to the action of the drug and the smoker becomes restless and irritable if he is deprived of tobacco. The greatest danger in the use of tobacco lies in the fact that a person may develop the habit of using it to excess. This may cause a rapid, irregular pulse, nervous diseases and digestive disturbances.

Smoking or using tobacco in any form is particularly harmful to young persons. It interferes with normal growth and weakens the heart; the whole body is slowly poisoned by the nicotine. It is easy to understand why boys and girls who are in training for athletics are not permitted to smoke. Would you expect a high school pupil that smokes habitually to excel in scholarship or in athletic competition?

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

alcohol
antiseptic
aseptic
bacilli
bacteria
cocci
epidemic
flagella
germs
nausea
nicotine
pulse
resistance
spirilla
stimulate

Write the number of each item on your paper and after it the word that completes the statement.

1. Microscopic plants are called ________.
2. Microscopic animals are called ________.
3. Bacilli are ________ shaped bacteria.
4. Tiny hairs projecting from the cell wall of certain bacteria are called ________.
5. A solution that kills disease germs is called an ________.
6. A substance that causes an increase in the activity of organs is known as a ________.
7. Tobacco contains a poison called ________.
8. Disease germs do not readily attack a healthy body because of: fumigation; disinfection; quarantine; respiration; its resistance.

Which item in each of the following lists does not belong with the others?

9. pneumonia; bacteria; cocci; protozoa; disease.
10. solution; aseptic; antiseptic; germs; Joseph Lister.

Which of these statements are true? If any are false, re-state them in correct form.

11. Rod-shaped bacteria are called protozoa.
12. All bacteria are harmful.
13. Bacteria reproduce by pollination.
14. Most germs that produce disease enter the body through the nose and mouth.
15. Nicotine is a deadly poison.

CHAPTER XXXIII

HOW CAN WE PROTECT OUR BODIES FROM HARMFUL GERMS?

Do you know:

How your government helps to protect your health? Why in some countries the bite of a mosquito kills the person it bites? That flies have killed many people? That a female fly may produce many flies in one season?

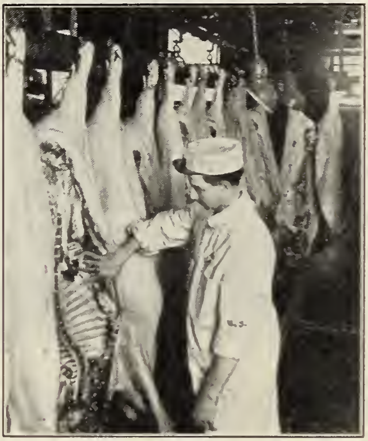
Why tuberculosis is sometimes called the "white plague"? That disease germs produce deadly poisons known as toxins? That vaccination has made smallpox an uncommon disease in our country? Why it is unnecessary for any child to have diphtheria? That diphtheria antitoxins are extracted from the blood of horses? That sunlight and pure air are the best aids in building a healthy body? Why sleep is necessary?

PROBLEM: HOW DOES OUR GOVERNMENT HELP TO PROTECT US FROM DISEASE?

No doubt your local government helps to protect you from disease by furnishing a supply of pure water, by making adequate provision for the disposal of garbage and sewage, and by keeping the streets clean. How does your local government provide for each of these? Name ways in which your local government helps to protect you from disease.

What habits of cleanliness should we all practice? As an individual you can do many things to prevent disease germs from entering your body. You can wash your hands with soap and water before each meal; brush your teeth at least once a day; refuse to drink from a cup used by another person until it has been washed; kill or arrest the growth of germs in cuts and bruises by the use of an antiseptic; guard your food in the home from dust and germs by keeping it covered and in a cool place; protect your friends and others in crowded rooms or public conveyances by covering your mouth and nostrils when you cough or sneeze.

You also have certain duties as a good citizen. It is your responsibility to do your part to see that the sanitary measures in your community are promptly and effectively carried out. In this chapter you will learn ways in which you can help to stamp out disease.



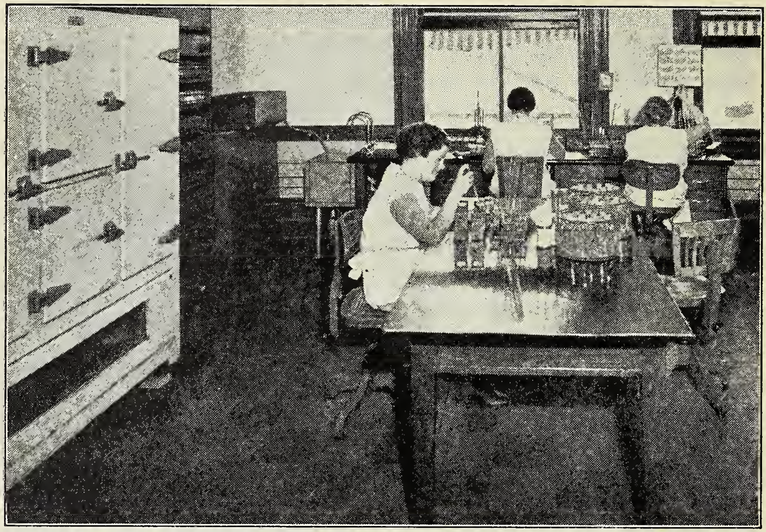
Courtesy U. S. Dept. of Agriculture

FIG. 378. The Federal Government provides for inspection of products in meat packing houses. Here a Federal inspector is making sure that pork meets government standards.

Why should food be inspected by the government? Before the pure food and drug act was passed by Congress in 1906, it was claimed that about fifty per cent of the food sold in the United States was adulterated. Food may be adulterated in several different ways: (1) by removing an ingredient, such as cream from milk, leaving the milk below a specified standard; (2) by adding a material that dilutes or weakens the product, such as adding cheaper and inferior ingredients to certain meat products; (3) by using a food preservative injurious to health, such as formaldehyde; and (4) by concealing the impurity or inferiority of a product through coloring, bleaching, or the use of special flavoring substances.

Whether food preservatives, such as benzoate of soda, are harmful to the body has not yet been agreed upon by experts in foods. They do agree, however, that the use of such preservatives and the practice of concealing their use are objectionable because they make possible the use of partially decayed foodstuffs containing poisons that were produced by bacteria before the preservatives were added.

The government inspects foods. Federal and local governments provide for inspection of plants manufacturing food products, such as packing houses (Fig. 378), bakeries, and canneries, to



Courtesy N. J. State Health Laboratories

FIG. 379. State governments help to protect us from disease. Specimens of all sorts from different parts of the state are analyzed in state health laboratories and reports made to the senders.

see that foods of all kinds conform to standards set by the government and that none of the labels on food products are misleading, and particularly whether any dangerous or habit-forming drug is a part of the product. States pass laws and cities pass ordinances requiring dealers to protect foods from dust, insects, and other means of infection. They even regulate the refrigeration of meats and the handling of food in hotels, restaurants, refreshment stands, and camps along highways.

We can do a great deal toward the maintenance of health by cooperating with governmental agencies in their attempts to promote health by insuring us a healthful food supply.

Other health-promoting activities of governments. The inspection of food is but one way in which the government helps to protect us from disease. Cities and states maintain health laboratories (Fig. 379). The national government employs hundreds of people who spend their lives in an attempt to discover the best means of ridding our country of disease. As you study the remaining pages of this chapter, notice the ways in which our government helps to promote sound health.

PROBLEM: WHY SHOULD WE DESTROY MOSQUITOES AND FLIES?

You learned from Experiment 163 that flies carry bacteria from place to place. Mosquitoes and other animals also spread bacteria. Hence, many diseases may be controlled by destroying animals which carry these germs.

Destroy the mosquito. During most of their lives, mosquitoes live on the juices of vegetable matter. But, at breeding time, the female needs animal protein for the growth of eggs, and therefore craves the blood of animals. When sucking blood, the mosquito injects a poison into the blood of the person bitten. This poison causes the blood vessels to expand, producing the "mosquito bite." It is the injection of harmful germs into the blood of an animal that makes it possible for mosquitoes to spread disease.

One disease spread by mosquitoes is malaria. Malaria germs are carried by the *anopheles* mosquito. When the anopheles mosquito sucks the blood of a person suffering from malaria, some of the malaria germs pass into the stomach of the mosquito. There they multiply rapidly and are carried to all parts of the mosquito's body. If such a mosquito bites a person, it injects some of these malaria germs into the blood stream of the victim and thus infects him with the disease. As malaria germs are spread in no other way, if all the anopheles mosquitoes were destroyed, malaria would never be communicated from one person to another.

The common mosquito, you no doubt know, is the *culex*. Although this mosquito does not carry malaria germs, it is very annoying.

Yellow fever is communicated by the mosquito called *stegomyia*. As the result of a determined effort to eradicate this insect, yellow fever is unknown almost in the United States and has nearly disappeared from many other parts of the world.

To destroy the mosquito, we must destroy its breeding places. The mosquito lays its eggs on the surface of stagnant water—ponds, mud holes, and rain barrels. In warm weather these eggs soon hatch into "wrigglers." In a few more days after certain changes (Fig. 380) the insect emerges a full grown mosquito and flies away.

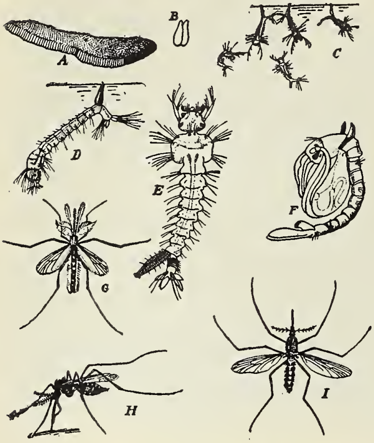


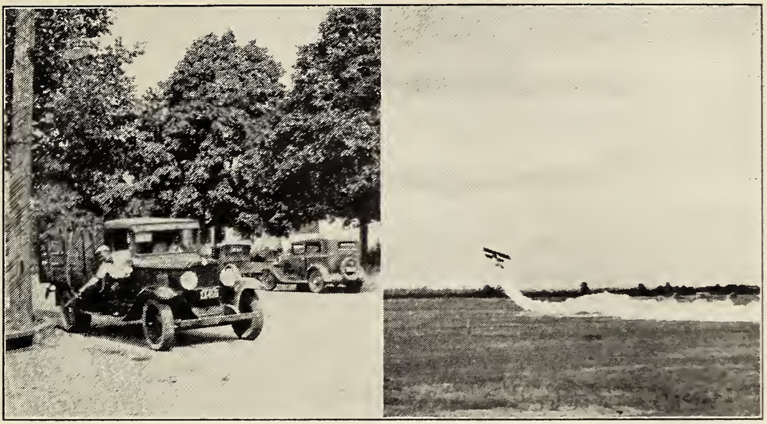
FIG. 380. Life history of a mosquito. *A*, egg raft; *B*, eggs; *C*, young "wrigglers" (larvae); *D* and *E*, more advanced stages of larvae; *F*, pupa; *G*, male; *H* and *I*, females. *D*, *E*, and *F* are enlarged slightly more than the others. (After Howard.)

To exterminate mosquitoes, water should not be allowed to stand in uncovered containers out of doors; swamps and puddles should be drained wherever possible, and oil should be poured on the surface of the water in those that cannot be drained (Fig. 381). A cheap oil poured frequently on a pond forms a film which suffocates the wrigglers by preventing them from getting air, and makes it impossible for the female adults to lay more eggs on the surface.

Swat the fly. The common housefly is a carrier of certain disease germs. Unless prevented, flies enter the kitchen and dining room; they do not hesitate to stand on any kind of filth one moment and on our food the next. The feet of a fly are well adapted to carry dirt and disease germs. What did your results in Experiment 163 prove about the ability of a fly to carry bacteria? One disease which is often spread by flies is typhoid.

"Swat the fly" is both popular and praiseworthy. But "Fight filth" is more so, for only through the elimination of filth will flies be exterminated. Flies must be kept away not only from sick people but also from healthy people. Explain how your home is protected from flies.

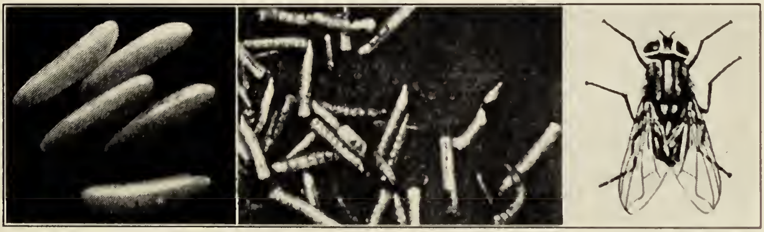
Careful studies show that most flies never travel more than half a mile from their breeding places. Consequently, the presence of flies indicates that there must be filth in which they can breed in the immediate neighborhood.



Courtesy U. S. Dept. of Agriculture

FIG. 381. Two methods of mosquito control. Open sewers sprayed with oil to prevent the growth of larvae. Swampy regions dusted with Paris green by airplane to control mosquitoes that carry malaria.

The fly develops through all the stages of an insect: from egg to larva, from larva to pupa, and from pupa to a full grown adult fly (Fig. 382). The presence of a single pair of flies under favorable conditions of temperature and food may result in the breeding of 350,000,000 flies in a few months. Every fly killed early in the spring, therefore, prevents the breeding of many. By preventing the accumulation of filth, by keeping garbage cans clean and covered, and by screening every house, we can eliminate the breeding places of the fly and keep food away from them. If all persons united to eliminate flies, they would soon cease to be a problem.



Courtesy U. S. Dept. of Agriculture

FIG. 382. Stages in the development of the house fly: eggs, twelve times natural size; larvae, about life size; and an adult fly.

PROBLEM: HOW CAN WE PROTECT OURSELVES AGAINST SOME DANGEROUS DISEASES?

Are colds dangerous to health? A cold is usually an indication that there is something wrong with your habits of living. It may mean that you have not been getting enough sleep or exercise; it may mean that your diet does not meet your needs; or it may mean that you have exposed your body to cold or wet. The reduced resistance of the body which leads to the contraction of a cold may be caused by worry, by sleeping or working in overheated or poorly ventilated rooms, or by overeating and by other excesses.

Remember that a cold is caused by germs that are able to develop because of a low bodily resistance. Because colds are so common, we frequently do not give them the attention we should. They should be regarded seriously not only because they are the forerunners of influenza, pneumonia, diphtheria, and tuberculosis, but also because they are an indication of wrong habits of living that should be corrected.

Resistance to tuberculosis. Much attention is now being paid to preventive measures against the great white plague, tuberculosis. The usual means for building up a strong bodily resistance to tuberculosis are as follows:

1. Abundance of fresh air, day and night.
2. Plenty of nutritious food, but not more than can be properly digested and assimilated.
3. Rest.
4. Exercise.
5. Sunshine.

You can see that the way to avoid tuberculosis is to follow the means used to build up a strong resistance to the disease. If a person does contract tuberculosis, his physician will direct him to follow these rules of living in an attempt to build up his resistance.

Tuberculosis germs can be spread easily. Care must be taken by people suffering from this disease to prevent the scattering of these germs when talking or coughing and to destroy all matter which might cause the spread of the disease. Cattle sometimes have tuberculosis. Milk and meat from such cattle may cause tuberculosis. Children are more susceptible to germs from this source than are adults. Due to the strict laws with reference to milk and meat inspection and handling, danger from milk and meat is becoming less all of the time.

Typhoid fever. The body wastes from a patient with typhoid fever contain billions of the germs that cause this disease. The only way in which an individual becomes infected is by getting germs from a typhoid fever patient into his food or drink.

As you have learned, flies often carry typhoid fever germs. A person caring for a typhoid fever patient must exercise great care in disinfecting his hands so that he will not carry the disease. Absolute cleanliness would prevent the spread of typhoid fever to a large extent. Typhoid fever epidemics were much more common before care was taken to insure a pure water supply and to prevent contamination of milk. Explain why. Certain people, called typhoid carriers, have these germs in their bodies all the time but their bodily resistance to them is strong enough to prevent the germs from reproducing in sufficient numbers to produce illness. However, a carrier may pass the disease along to others.

Smallpox. No doubt you have been vaccinated for smallpox. In the early history of our country, this dreaded disease was very common and resulted in the death of many people. Vaccination has practically freed us from smallpox.

The credit for conquering smallpox belongs to an English physician, Edward Jenner. It had been known for some time that dairymaids occasionally contracted a disease called cow-pox, from cows, which closely resembled smallpox. It was further observed that persons who had had cow-pox did not get smallpox, that is, they did not contract smallpox when exposed to the disease. In 1798 Dr. Jenner first made use of this relation between the two diseases by taking some of the matter from a cow-pox sore on the arm of a dairymaid and putting it into scratches he made on the arm of an eight-year-old boy. Sores developed on the boy's arm which healed to form scars much like our vaccination marks.

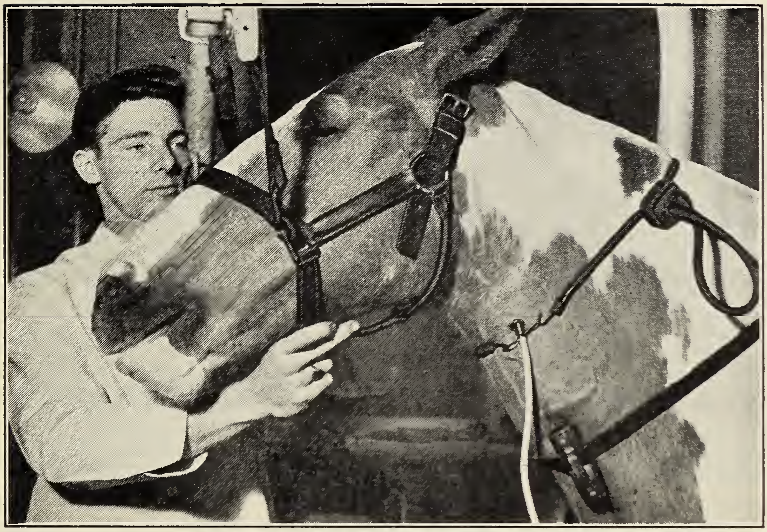
Later, Dr. Jenner exposed the boy to smallpox, but he did not take the disease. The *vaccination* had protected him from the smallpox germs.

To prepare the *vaccine* with which human beings are vaccinated for smallpox, calves from two to four months old are used. These calves are kept in a healthy condition and are very carefully cared for. They are vaccinated with smallpox germs, which lose much of their vitality in the calf. Some of the weakened germs are taken from the calf and used to prepare vaccine. This vaccine is placed in a scratch on the arm or leg of the person to be vaccinated; the germs grow and produce in the person a mild case of smallpox. The body develops a resistance to these germs which protects it for several years from smallpox.

Diphtheria. Diphtheria germs develop in greater numbers in the throat than in any other part of the body. Toxins (poisons) are formed which inflame the throat and pass into the blood, causing high fever and headache. The toxins stimulate the cells of the body to form *antitoxin,* a substance which tends to neutralize the poisons of the bacteria. By giving the patient more antitoxin, physicians aid the body cells in their efforts to throw off the effects of the toxin. Diphtheria antitoxins are made by inoculating a young, healthy horse with toxins (Fig. 383). The antitoxins are then separated from the blood serum drawn from the jugular vein of the horse.

As diphtheria germs are often present in the throat of a person who does not have the disease, it is dangerous to use drinking cups and towels used by another. Diphtheria is usually transferred by contact but it may be acquired by simply being in a room occupied by a person ill with the disease. Consequently, homes should be disinfected after a case of the disease. Find out what methods can be used to make a person immune to diphtheria.

Why should homes be quarantined? Quarantine comes from the Latin word meaning *forty,* and originated from the custom of holding up vessels from coming into port for a period of forty days if a person afflicted with plague was on the ship. We use the term now not only with respect to ships but also for the enforced isolation of any person or place infected with a contagious disease.



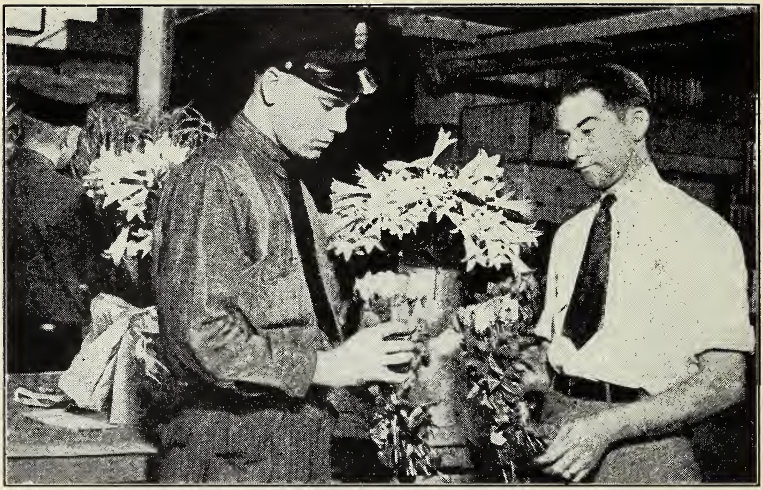
Life Magazine

FIG. 383. Blood to be used in preparing serum is being removed from the horse through the white tube attached to his neck.

All ships entering United States ports from foreign lands are inspected by physicians in the employ of the Federal Government, and if contagious diseases are found, the ship and passengers are held in quarantine until the United States health authorities are satisfied all danger of contagion is past.

In homes if a contagious disease develops, such as typhoid fever or diphtheria, the law requires that the disease must be reported by the attending physician to the health officer whose duty it is to place a placard on the front door warning people of the presence of the disease. All citizens should cooperate with health authorities in respecting and obeying laws that pertain to quarantine. The isolation of a person with a dreaded disease is an old custom dating back thousands of years to the time when victims of leprosy were refused admittance at the gates of a city and forced to live outside its walls.

Probably while touring on a public highway you have been stopped by an officer who inquired whether you were transporting certain vegetables or other plants. If so you became aware of



Courtesy Bureau of Plant Quarantine, U. S. Dept. of Agriculture

FIG. 384. Government inspectors examining cut flowers to make sure there are no Japanese beetles present.

a quarantine on plants. Quarantines have recently been in operation against the corn borer and the Japanese beetle (Fig. 384).

Disinfection. After a person has had an infectious disease such as diphtheria or scarlet fever, the harmful microbes in the room, clothing, and bedding of the sick person should be destroyed. The destruction of microbes by means of chemical solutions, such as carbolic acid, bichloride of mercury, or active chloride of lime, is referred to as disinfection. Clothing boiled in water or exposed to sunlight is usually sufficiently disinfected as these treatments will kill most disease bacteria in a few minutes.

Fumigation. Sometimes poisonous gases are set free in rooms that have been occupied by sick persons. This process is called *fumigation* and is designed to disinfect furniture, rugs, and wall paper. The simplest way to fumigate a room is to seal it as airtight as possible and burn sulfur in it. The burning sulfur liberates a poisonous gas, sulfur dioxide. Formalin, a poisonous liquid which when heated liberates the poisonous gas formaldehyde, is also used for fumigating purposes. Your doctor will advise you when it is necessary to fumigate a room.

PROBLEM: WHAT IS NATURE'S FORMULA FOR A HEALTHY BODY?

Sunlight and pure air. Two factors in good health are sunshine and pure air, both easily obtained by most people, and less expensive than any other commodity or service that we can buy. The sun furnishes its health-giving rays free to all who will take time to receive them. The rays of sunlight are powerful destroyers of germs. We picture robust health in terms of ruddy cheeks and skin tanned by exposure to direct sunlight. Those who suffer from certain bone diseases, such as rickets, can greatly improve their health by judicious exposure to sunlight. Even victims of tuberculosis are sometimes helped greatly in the same way.

The most immediate need of a human being is for pure air. We might live for hours without drinking. Some persons claim to have lived forty days without food. But we could not safely risk our lives two minutes without oxygen. It is the oxidation of materials in the cells that releases energy for all the functions of the body. Our need for oxygen is well taken care of in summer by outdoor life and open windows. In winter, however, when we live almost entirely indoors, often in poorly ventilated rooms, the absence of pure air affects our health. Cheeks lose their color; the skin turns pale; digestive disorders frequently bother us; and we are subject to colds. To maintain good health in winter we should get out into the sunshine whenever possible, and see that the rooms in which we live and work are properly ventilated and kept at a temperature of 68° to 70° F. The air must be kept sufficiently moist, and windows should be open when we sleep.

Wholesome food. As you learned in the study of foods, a large percentage of bodily ills can be traced to an unbalanced diet. What are the various kinds of food that are needed for a balanced diet?

Healthful exercise. The human body tends to adapt itself to its environment. The arm muscles of a blacksmith become strong through the use he makes of them. Men who train consistently for long distance running develop strong respiratory systems and general bodily endurance. A person able to play games such as tennis, golf, basketball, baseball, and football usually improves his bodily resistance to disease and increases his strength. The body of the person who does not exercise becomes soft and flabby. The best exercise, especially for girls and boys, is some form of play. Playing a variety of games develops nearly every muscle. In your daily work certain muscles that should be developed may get no exercise. The best forms of exercise are those taken in fresh air and sunlight. It is interesting to watch a spirited game from the bleachers, but do not be content to remain always on the bleachers. For the health of the body it is necessary to take part in games and engage in vigorous exercise. Swimming and tennis are excellent forms of exercise, especially when taken in the sunlight and open air.

Exercise should be suited to the strength of the heart. Your physician can advise you as to the kinds of games best suited to your physical development. Exercise should be light at first and gradually increased until it becomes as vigorous as your body needs for the proper development of the various organs and bodily functions. There are other reasons for exercising. The efficient body is pliant and graceful as well as filled with energy. Complete control over bodily movements indicates a calm and well controlled nervous system.

Plenty of sleep. As an electric current recharges electric cells, so sound sleep restores vigor to the cells of the body. Physical and mental work reduce the vitality of muscles, brain, and nerves. Sleep is nature's method of restoring the body to its normal vitality. Sleep should be undisturbed if it is to restore the needed bodily vigor. Hence night is the best time to sleep. Our busy lives during the day, the temptation or the necessity of working at night and the temptation of alluring entertainments after working hours rob many of us of sufficient hours of sleep. Individual needs differ but it is generally agreed that children in elementary school should have from ten to twelve hours of sleep; that high school students should have nine or more hours; and that adults should have seven or eight hours. If you do not sleep soundly, try to discover the reason. It may be that your diet is unbalanced, or your evening work or play is too strenuous.

Our study in this course has led us to observe some of the laws of nature, especially those that affect our everyday life. We have seen how natural forces and the interaction of elements have deposited vast mineral resources within the earth; how they have furnished energy and matter for the growth of plant life; and how plant life in turn furnishes food, clothing, and shelter for man and beast. Let us make our lives efficient and happy by maintaining our health as nearly perfect as possible. The formula is: sunlight and pure air, wholesome food, healthful exercise, agreeable work, plenty of sleep, and a helpful, kindly, and sympathetic attitude toward our fellows.

A Self-Test

From your study of this chapter you should have learned the meaning and spelling of the following words. Test yourself.

anopheles
antitoxin
benzoate
culex
disinfection
fumigation
malaria
microbe
quarantine
stegomyia
tuberculosis
vaccination

Write the number of each item on your paper and after it the word that completes the statement.

1. Malaria germs are carried by the ———— mosquito.
2. The common mosquito is called the ————.
3. The ———— mosquito carries yellow fever germs.
4. To destroy mosquitoes we must destroy their ———— places.
5. The credit for conquering smallpox belongs to ————.
6. Destruction of microbes by means of chemical solutions is called ————.
7. Setting poisonous gases free in rooms to kill germs is called ———.

Which of these statements are true? If any are false, re-state them in correct form.

8. Bacteria produce antitoxins in the body.
9. The United States government safeguards our food.
10. The mosquito carries typhoid fever germs.
11. Quarantine should follow fumigation.
12. Air is the most immediate need of man.

THOUGHT EXERCISES FOR UNIT XVI

PRINCIPLES OF SCIENCE

State the principles of science in this unit in sentence form. One of them is: Disease bacteria produce poisons in the body called toxins.

QUESTIONS OR PROBLEMS

1. Some folks become alarmed at the mention of the word "microbe." Why?
2. Are bacteria parasites? Give reasons for your answer.
3. What makes it possible to preserve meat and fruit by pickling?
4. Why will dried beef keep for a long time?
5. Describe the conditions under which bacteria multiply rapidly.
6. Persons live healthy lives for years even though disease germs are always present. How is this possible?
7. Should growing children drink tea and coffee? Discuss your answer.
8. Why are athletes required to abstain from smoking?
9. Is alcohol a food? Give reasons for your answer.

PROJECTS AND REPORTS

1. Find out what organizations have authority over health conditions in your community. Interview a member of each organization if possible. Report to class on their duties, and on the regulations that should be observed by citizens.
2. Make a survey of your community and report to class any conditions concerning possible breeding places for flies and mosquitoes. Explain why these places are likely to breed such pests.

REFERENCES FOR READING AND STUDY

1. Adams, Carl W., *Your Teeth and Their Care.* The C. V. Mosby Company, St. Louis.
2. Barker, Lewellys F., *Live Long and Be Happy.* D. Appleton-Century Company.
3. Broadhurst, Jean, and Lerrigo, Marion Olive, *Health Horizons.* Silver Burdett Company.

GLOSSARY

This is a list of the important scientific words in this text, together with the pronunciation and definition of each word and the number of a page on which each is discussed.

The definition in the glossary is not the same as the one given in the text in all cases, but it gives the same idea. After you have read a definition in the glossary you should turn to the page indicated and read the discussion there in order to obtain a more complete meaning of the word.

acid (as'id): a compound of hydrogen, has a sour taste in a solution of water, turns blue litmus red, and neutralizes alkalies. (p. 260)

adhesion (ad he'zhun): the attraction of molecules of different kinds for each other, as the attraction between molecules of glue and wood. (p. 287)

adulterate (a dul'ter ate): (food) to add or remove materials which cheapen it; to add preservatives which are injurious to health; to conceal impurity or inferiority through coloring, bleaching, or flavoring. (p. 669)

air conditioning: regulation of temperature, humidity, and purity of air. (p. 97)

alchemists (al'kem ists): early chemists who searched for a method of changing common metals like iron into gold. (p. 6)

algae (al'je): a group of the simplest non-flowering plants; they are green, blue-green, red, purple, and brown. (p. 549)

alkali (al'ka li): a compound which has a soapy feeling, has a bitter taste, turns red litmus blue, and neutralizes acids. (p. 262)

alloy (al loy'): a mixture of two or more metals melted together. (p. 259)

alternating (al'ter na ting) **current**: an electric current which flows through a conductor first in one direction and then in the opposite direction. (p. 451)

altimeter (al'ti me ter): an instrument used to determine distance (altitude) above sea level. (p. 19)

altitude (al'ti tude): elevation (distance) above sea level. (p. 17)

ammeter (am'meter): an instrument used to measure an electric current in amperes. (p. 436)

ammonia (a mo'nia): a substance that is composed of nitrogen and hydrogen and is used as a refrigerant in the manufacture of ice. (p. 95)

amoeba (a me'ba): a very small one-celled animal. (p. 572)

ampere (am'peer): a unit of electric current. (p. 436)

amphibian (am fib'i an): an animal which in early life has gills and lives in the water; later it develops lungs and lives on land. (p. 590)

anemometer (an e mom′e ter): an instrument used to measure the velocity of wind. (p. 138)
aneroid (an′er oid) **barometer:** a kind of barometer in which the atmospheric pressure, in bending the top of partially exhausted metal box, causes a pointer to move. (p. 18)
anopheles (a nof′e lez): a species of mosquito that carries the germs causing malaria. (p. 671)
antenna (an ten′a): a device for sending or receiving radio waves. (p. 490); feeler of an insect. (p. 582)
anthracite (an′thra site): hard coal. (p. 340)
anticyclone (an′ti si klone): a very large whirling body of air, of high barometric pressure, which moves slowly across the country usually from west to east. (p. 143)
antiseptic (an ti sep′tik): a substance which kills disease germs or prevents their growth. (p. 661)
antitoxin (an ti tok′sin): a substance produced in the body which tends to neutralize poisons produced by disease germs. (p. 676)
aorta (a or′ta): the largest artery in the body. (p. 638)
argon (ar′gon): an inactive gas in the atmosphere, sometimes used to fill electric lamps. (p. 40)
armature (ar′ma chur): a part of an electric generator or motor made up of coils of wire which rotate between magnetic poles. (p. 451)
artery (ar′ter y): any blood vessel which carries blood from the heart to the capillaries. (p. 638)
arthropod (ar′thro pod): a large group of animals, all of which are "jointed-footed," includes insects, spiders, lobsters, crabs, etc. (p. 581)
assimilation (a sim i la′shun): absorption of food by a cell from the blood. (p. 635)
astigmatism (a stig′ma tizm): a defect in the curvature of the eye ball or lens which causes a blurred image. (p. 423)
atmosphere (at′mos fear): the mixture of gases (air) which surrounds the earth. (p. 11)
atom (at′om): the smallest particle or sub-division of an element. (p. 254)
axis (ax′is): an imaginary line running through a body from pole to pole, as the axis of the earth. (p. 192)

bacteria (bak te′ri a): a group of very small plants some of which cause diseases. (p. 509, 553, 655)
barograph (bar′o graf): an aneroid barometer which is self-registering. (p. 19)
barometer (ba rom′e ter): an instrument used to measure the pressure of the atmosphere. (p. 15)
base: a compound, bitter in taste, which turns red litmus blue, and neutralizes acids. (p. 262)
bast: layer of tough fiber-like cells in the bark of stems. (p. 521)
bathysphere (bath′i sfear): a strongly built sphere from within which scientists study life deep in the ocean. (p. 36)
battery (bat′er y): two or more electric cells connected together so that they can be operated as one unit or cell. (p. 436)
Bessemer converter: furnace used to change cast iron to steel. (p. 270)

biology (bi ol'o jy): a study of both plant and animal life. (p. 574)

bituminous (bi tu'mi nus) **coal**: soft coal. (p. 340)

budding: grafting plants by means of buds. (p. 525)

buoyant (boi'ant) **force**: the upward pressure exerted by a fluid on a floating body. (p. 105)

caisson (ka'son): a large steel cylindrical air chamber in which men work under water. (p. 34)

calcium (kal'si um): an element which is a metal. (p. 271)

calorie (kal'o ry): the quantity of heat which is necessary to raise the temperature of one gram of water one degree centigrade. One thousand calories is a large Calorie. (p. 359)

calyx (ka'liks): the part of a flower consisting of all the sepals. (p. 528)

cambium (kam'bi um): the growing layer of a woody stem. (p. 522)

candle power: unit for measuring the intensity (brightness) of light. (p. 388)

capillaries (kap'i ler iz): very small blood vessels which conduct blood from the arteries to the veins. (p. 638)

capillarity (kap i lar'i ty): the tendency of liquids to rise into small tubes or small openings. (p. 288)

carbohydrate (kar bo hi'drate): a compound, food, composed of carbon, hydrogen, and oxygen. (p. 237)

carbon dioxide (di ox'ide): CO_2, a gaseous compound composed of carbon and oxygen. (p. 41, 349)

carbon monoxide (mon ox'ide): CO, a very poisonous gaseous compound composed of carbon and oxygen. (p. 349)

carburetor (car'bu ra tor): a device on a gas motor engine for changing liquid fuel into vapor and for mixing the vapor with air. (p. 302)

caterpillar (kat'er pil er): the larva or wormlike stage of moths and butterflies. (p. 583)

cell: (biological) the unit structure of plants and animals. (p. 508); (electrical) a device for changing chemical energy into electrical energy. (p. 434)

cellulose (sel'u los): the substance forming cell walls and wood of plants; it is widely used in the manufacture of paper, rayon, and other materials. (p. 545)

centigrade (sen'ti grade): the temperature scale on which there are one hundred divisions between the freezing point and boiling point of water. (p. 356)

centrifugal (sen trif'u gal) **force**: the force which operates on a body moving in a circular orbit (path) and tends to cause the body to fly off in a straight line. (p. 284)

centimeter (sen'ti me ter): a unit of length in the metric system, 2.54 centimeters equals 1 inch. (p. 313)

chemical (kem'i kl) **change**: any change in the composition of matter. (p. 252)

chlorophyll (klo'ro fil): the substance which gives green plants their color. (p. 514)

choroid (ko'roid): a coat of the eye. (p. 420)

circuit: (electrical) an endless conductor through which electrons flow. (p. 433)

circulatory (sur′ku la to ry) **system:** the network of tubes by means of which the blood of an animal or the sap of a plant is carried through all parts of the animal or plant. (p. 638)

cirrus (sir′us) **cloud:** high, thin, thread-like cloud. (p. 133)

climate (kli′mat): the average condition of atmosphere in a region over a period of several years. (p. 116)

coagulation (ko ag u la′shun): the thickening of a liquid such as the thickening of blood, the changing of a liquid to a jelly-like substance. (p. 546)

coal gas: a gaseous fuel made by roasting bituminous (soft) coal in an air tight furnace. (p. 344)

cohesion (ko he′shun): the attraction of same kind of molecules; causes the molecules of a substance to stick together. (p. 286)

combustion (kom bus′chun): burning. (p. 45)

comet (kom′et): a body seen in the sky with a bright head and usually with a less bright tail. Comets move in fixed orbits. (p. 187)

commutator (kom′u ta tor): a device on a direct current motor or generator which keeps the electric current flowing in the proper direction. (p. 463)

compass (kum′pas): an instrument in which a strongly magnetized needle is balanced on a pivot; used for determining the directions. (p. 442)

compound (kom′pound): a substance formed by the chemical union of two or more elements. (p. 257)

concave (kon kave′): curving inward like the inside of a bowl. (p. 412)

condensation (kon den sa′shun): the changing from a gas or vapor to a liquid or solid as water vapor changing to water or ice. (p. 44, 90)

conductor (kon duk′tor): a substance through which heat energy or electrical energy passes. (p. 429)

constellation (kon stel a′shun): a group of stars whose imaginary outline represents a mythological personage, animal, or object. (p. 184)

convection (kon vek′shun): the transfer of heat through gases or liquids by movement of molecules in the material. (p. 370)

convex (con vex′): curving outward like the outside of a ball. (p. 412)

cornea (korn′e a): the front part of the outer coat of the eye ball. (p. 420)

corolla (ko roll′a): part of a flower made up of all the petals. (p. 528)

corpuscle (kor′pusl): a very small body; examples, the red and white blood cells. (p. 636)

cortex: bark of a root. (p. 516)

cotyledon (kot i le′dun): seed leaf; storehouse for food for embryo in seed. (p. 533)

culex (ku′lex): the common mosquito. (p. 671)

cumulus (kum′u lus) **cloud:** thick dome-shaped cloud. (p. 133)

cyclone (si′klone): a slowly whirling large body of air of low barometric pressure; it moves slowly across the country, usually from west to east. (p. 141)

density (den′si ty): usually the weight in pounds of a cubic foot, or the weight in grams of a cubic centimeter of a substance. (p. 107)

developer: a chemical solution used in developing a photograph. (p. 415)

dew point: the highest temperature at which water vapor in air condenses as dew, fog, or frost. (p. 129)

diaphragm (di'a fram): muscular partition separating the chest cavity from the abdomen, (p. 641); in sound it may be a thin vibrating disk or membrane. (p. 61)
dicotyledon (di kot i le'dun): a seed with two cotyledons. (p. 534)
diffusion (di fu'zhun): the reflection of light in all directions. (p. 410)
digestion (di jes'chun): the process of changing foods into liquid form which can be absorbed by the body. (p. 630)
diphtheria (dif the'ri a): a dangerous, contagious disease of the throat. (p. 676)
direct current: movement of electricity through a conductor in one direction only. (p. 451)
disease (di zeez'): any state or condition of the body of a plant or animal which interrupts or interferes with life processes. (p. 658)
disinfection (dis in fek'shun): the destruction of disease germs by means of chemical solutions. (p. 678)
distillation (dis ti la'shun): a twofold change by which a liquid is turned into a gas and then condensed into a liquid. (p. 91)
doldrums (dol'drumz): a wide region on both sides of the equator where there is little wind. (p. 140)

echo (ek'o): repetition of a sound caused by reflection of sound waves. (p. 57)
eclipse (e klips'): the shutting off of light from the sun or moon or other body by the intervention of some opaque body, as an eclipse of the sun by the passage of the moon between the sun and earth. (p. 177)
efficiency (e fish'en sy): the ratio of the work done by a machine to the total work put into the machine. (p. 329)
elasticity (e las tis'i ti): the ability of a body to regain its original shape or size after it has been bent, compressed, or stretched. (p. 287)
electrode (e lek'trode): a pole of an electric cell or generator. (p. 434)
electrolysis (e lek trol'i sis): the decomposition of a substance such as water by means of an electric current. (p. 84)
electromagnet (e lek tro mag'net): a magnet formed by passing a current of electricity through a coil of wire wound around a soft iron core. (p. 448)
electron (e lek'tron): a particle of negatively charged electricity. (p. 255, 429)
electroplating: process of plating a substance with a metal by means of electricity. (p. 470)
electrotyping: a process of using electricity to make a printing plate from type. (p. 471)
element (el'e ment): a substance that cannot be broken up into simpler substances. (p. 254)
embryo (em'bre o): a fertilized egg cell at rest or in process of developing into a plant or animal. (p. 530)
energy (en'er jy): the ability to do work. (p. 280)
environment (en vi'ron ment): the external surroundings or influences affecting the life and development of a plant or animal. (p. 1)
enzyme (en'zime): a substance which causes a chemical change without undergoing change itself. (p. 633)
epidermis (ep i der'mis): tissue forming outer layer of a leaf. (p. 512); of a root (p. 516)

equator (e kway'tor): an imaginary line which extends around the earth halfway between the north and south poles. (p. 197)

erosion (e ro'zhun): the wearing away of rocks and soil by the action of wind, water, and heat. (p. 218)

esophagus (e sof'a gus): food tube leading from mouth to stomach. (p. 632)

ether: a substance which is assumed to fill all space. (p. 403)

evaporation (e vap o ra'shun): the changing of a liquid or solid to vapor by the action of heat. (p. 43)

Fahrenheit (far'en hite): the temperature scale on which the freezing point of water is 32° and the boiling point of water is 212°. (p. 356)

fat: food composed of carbon, hydrogen, and oxygen. (p. 612)

fault: a break and dislocation of a layer of rock one part having been moved up or down from the other. (p. 225)

fermentation (fer men ta'shun): action of yeast plants on sugars; includes action of other ferments, as in the souring of milk and in the formation of vinegar from cider. (p. 559)

fertilization (fer ti li za'shun): union of a sperm cell with an egg cell to form a fertilized egg cell. (p. 530)

fertilizer (fer'ti lizer): a plant food which is added to soil. (p. 239)

fiber (fi'ber): a very small thread or the thread-like tissue of plants. (p. 521, 542)

fibrin (fi'brin): protein substance in the blood which assists in forming a clot. (p. 638)

filament: thin wire in an electric lamp, (p. 398); or a radio tube, (p. 487); or stem of a stamen. (p. 528)

filter (fil'ter): to allow a liquid to drain through a porous material which removes small solid particles from the liquid. (p. 73)

flagella (fla jel'la): tiny hairs projecting from cell walls of bacteria. (p. 656)

focus (fo'kus): a point at which refracted rays of light converge. (p. 412)

food: materials used by plants and animals in building tissue and generating energy. (p. 606)

foot-pound: the amount of work necessary to raise 1 pound through a vertical distance of 1 foot. (p. 313)

force: anything that causes a body at rest to move, or a moving body to change direction or velocity. (p. 280)

fossil (fos'il): the hardened remains or forms of ancient plants or animals preserved in rock. (p. 213)

freezing point: the temperature at which a liquid changes to the solid state. (p. 356)

frequency (fre'kwen sy): the number of vibrations made by a body in one second or the number of electrical discharges in one second. (p. 54)

friction (frik'shun): the resistance caused by moving one body against another or through a gas or a liquid. (p. 351)

fulcrum (ful'krum): support or pivot about which a lever turns. (p. 318)

fumigation (fum i ga'shun): process of setting poisonous gases free in rooms to kill disease germs. (p. 678)

fungus (fun'gus), plural **fungi:** the group of simple plants that do not have chlorophyll. (p. 552)

fuse: to melt; also a device used in electrical circuits to protect them in case too much current passes through them. (p. 459)

fusion: the change from a solid to a liquid form. (p. 364)

galvanometer (gal van om′eter): an instrument used to detect feeble electric currents. (p. 449)

gastric (gas′trik) **juice:** a digestive fluid in the stomach. (p. 633)

generator (jen′er a tor): a machine in which coils of insulated wire cut through a magnetic field and produce electricity. (p. 450)

germ (jurm): a very small plant or animal organism which may produce disease. (p. 658)

germination (jur mi na′shun): the early stages of growth of the embryo (living part) in a seed. (p. 532)

geyser (gi′zer): a hot spring which throws out boiling water and steam at regular or irregular intervals. (p. 226)

glacier (glay′sher): a large or small body of slowly moving ice. (p. 216)

gland: an organ of the body which secretes a fluid that is used by the body or expelled from it. (p. 631)

grafting (graft′ing): to insert a bud or branch of a plant into the stem of another plant so that the bud or branch may grow as part of that plant. (p. 525)

gravity (grav′i ti): force of attraction between the earth and all other objects. (p. 290)

grid: in a radio tube, a network of fine wire. (p. 489)

guard cells: cells which regulate flow of gases through stomata of leaves. (p. 513)

hard water: water which does not form suds readily with soap; usually caused by the presence of certain compounds of either calcium or magnesium. (p. 76)

heat: a form of energy. (p. 336)

heat of fusion (fu′zhun): heat required to melt one gram of a solid without raising its temperature. (p. 365)

heat of vaporization (va por i za′shun): heat required to change one gram of a liquid to vapor without change of temperature. (p. 367)

helium (he′le um): one of the rare gaseous elements of the atmosphere; colorless, inactive and lighter than air. (p. 40)

hemoglobin (he mo glo′bin): a red material found in the red corpuscles of blood. (p. 636)

hormone (hor′mōne): chemicals secreted by certain glands of the body. (p. 643)

horse latitudes: the belt of calms between 30° and 35° north and south latitudes. (p. 140)

horsepower: unit of power; it equals 33,000 foot pounds per minute of work. (p. 315)

humidity (hu mid′i ty): amount of water vapor in the air. (p. 126)

hurricane (hur′i cane): a storm similar to a cyclone, though much more violent; usually occur over tropical waters near the West Indies. (p. 146)

hybrid (hi′brid): a plant or an animal bred by the crossing of two species. (p. 538)

hydra (hi′dra): a small fresh-water animal. (p. 576)
hydraulic (hi draul′ik) **press:** a machine in which pressure is transmitted through a liquid. (p. 103)
hydrocarbon (hi dro kar′bon): a compound that is composed of carbon and hydrogen. (p. 346)
hydrochloric (hi dro klor′ik) **acid:** an acid composed of hydrogen and chlorine; one of the gastric juices. (p. 261)
hydrometer (hi drom′e ter): an instrument used to determine the specific gravity of a liquid. (p. 472)

igneous (ig′ne us) rock: rocks formed by volcanic action and intense heat of the interior of the earth. (p. 207)
immune (i mune′): protected against any particular disease. (p. 664)
incandescent (in kan des′ent): luminous, white-hot, or glowing with heat. (p. 393)
induction (in duk′shun): the method of magnetizing iron or steel by bringing it into a magnetic field; the method of producing electric current in a conductor by moving the conductor through a magnetic field. (p. 443)
inertia (in er′sha): the tendency of a body in motion to remain in motion; or the tendency of a body at rest to remain at rest. (p. 283)
infectious (in fek′shus) disease: a disease which can be passed from one person to another. (p. 678)
inoculate (in ok′u late): to vaccinate a person against a disease. (p. 7)
insulator (in′su la tor): (heat) anything that is not a good conductor of heat; (electricity) anything that is not a good conductor of electricity. (p. 429)
intestine (in tes′tin): large and small, that part of the food canal between the stomach and the anus. (p. 633)
invertebrate (in ver′te brate): an animal having no spinal column or inside skeleton. (p. 575)
iodine (i′o dine): an element; dissolved in alcohol it forms tincture of iodine. (p. 662)
iris (i′ris): the part of the eyeball that regulates the amount of light entering the eye. It gives the eye its color. (p. 420)
iron: an element which is a metal; the chief element in steel. (p. 269)
irrigation (ir i ga′shun): watering land for agricultural purposes by means of canals and ditches. (p. 234)

kilowatt (kil′o wot): a unit of electrical power, 1,000 watts. (p. 456)
kindling temperature (tem′per a chur): the temperature at which a material begins to burn. (p. 46)
kinetic (kin et′ik) **energy:** the energy possessed by a moving body. (p. 281)

larva (lar′va): the wormlike form in which certain kinds of insects hatch from eggs. (p. 583)
larynx (lar′inx): voice box; organ containing the vocal cords. (p. 63)
latex (la′teks): a milky juice taken from certain plants; usually the raw material from which rubber is made. (p. 546)
latitude (lat′i tude): distance measured in degrees on the surface of the earth north or south of the equator. (p. 198)

leguminous (le gu′mi nus) **plant:** a plant on whose roots bacteria grow which have the ability to make nitrates from the free nitrogen of the air; some of the plants are peas, beans, clover, and alfalfa. (p. 240)
lens (lenz): a transparent body (usually glass) with one or two curved sides used to refract light. (p. 412)
lever (le′ver): a bar arranged to turn about a pivot or fulcrum. (p. 318)
lichen (li′ken): a low form of plant life which grows on rocks, trees, and moist soil. (p. 216)
light: a form of radiant energy. (p. 386)
light year: distance light travels in one year. (p. 181)
liver: an organ of the body which secretes bile and causes changes in sugar and other substances in the blood which pass through it. (p. 634)
loam (lom): a kind of soil; a mixture of clay and sand rich in organic matter. (p. 229)
lodestone (load′stone): a rock that is a natural magnet. (p. 439)
longitude (lon′ji tude): distance measured in degrees east or west of the zero (prime) meridian on the earth's surface. (p. 198)
luminous (lu′mi nus): giving off light, as the sun or an electric light. (p. 396)

machine (ma sheen′): a device to aid man in doing work. (p. 316)
magnet (mag′net): a piece of iron or steel that will attract other pieces of iron and steel. (p. 439)
magnetic field: space around a magnet which contains lines of magnetic force. (p. 445)
mammal (mam′al): an animal that produces milk to feed its young. (p. 595)
matter: the general name given to materials of all kinds; anything that occupies space and has weight. (p. 249)
mechanical (me kan′i kl) **advantage:** ratio of weight lifted to the force applied to a machine. (p. 321)
medullary (med′u lary) **rays:** cells that store food and form a means of communication between the inner and outer parts of a stem. (p. 522)
melting point: the temperature at which a substance begins to melt. (p. 364)
membrane (mem′brane): a thin tissue in plants or animals. (p. 641)
meridian (me rid′i en): an imaginary line which extends from pole to pole over the earth's surface. (p. 198)
metallurgy (me′tal urgy): the separation of metals from their ores. (p. 267)
metamorphic (met a mor′fik) **rock:** sedimentary or igneous rock that has been changed by heat and pressure. (p. 213)
metamorphosis (meta mor′fa sis): change of form of an animal as it develops from egg to adult stage. (p. 582)
meteor (me′te or): a body made luminous from the heat generated by its passage through the atmosphere. (p. 188)
meteorite (me′te o rite): solid material of a meteor which has fallen to the earth. (p. 188)
microbe (mi′crobe): a minute plant or animal. (p. 654)
microphone (mi′kro fone): a device for receiving and transmitting sound vibrations. (p. 490)
mineral (min′er al): an element or compound found in the earth, (p. 213); a compound found in food. (p. 615)

mixture (mix'chur): two or more intermingled materials each of which retains its original properties. (p. 258)

molds: a certain kind of fungus plants. (p. 553)

molecule (mol'e kule): the smallest unit of a compound. (p. 257)

mollusks (moll'osks): animals with soft bodies usually living within hard shells. (p. 586)

monsoons (mon soons'): winds which blow in one direction one season and in the opposite direction another season. (p. 139)

monocotyledon (mon o cot i le'don): a seed with one cotyledon. (p. 534)

motor (mo'ter): a machine for transferring the kinetic energy of moving water or the energy of an electric current into mechanical energy for doing work. (p. 462)

nebula (neb'u la): a luminous mass of matter in space. (p. 183)

neon (ne'on): an inactive gas in the atmosphere, used in electric signs. (p. 40)

nervous (ner'vus) **system:** all the nerves of the body, including the brain and spinal cord. (p. 644)

neurone (nu'rone): a nerve cell and connections. (p. 644)

neutralization (nu tral i za'shun): the counteraction of one substance by another, as an acid counteracts a base. (p. 264)

nimbo-stratus cloud: dark gray rain cloud. (p. 134)

nonconductor (non kon duk'tor): a substance which is a poor conductor of an electric current, or a substance which is a poor conductor of heat. (p. 429)

nucleus (nuk'le us): the central part of an atom, (p. 255); the denser, usually central part of a plant or animal cell. (p. 508)

ohm (ome): the unit of resistance in electrical measurements. (p. 437)

open-hearth furnace: a furnace for changing castiron into steel. (p. 271)

opaque (o pake'): not transparent to light. (p. 392)

optic nerve: the nerve of sight. (p. 420)

orbit (or'bit): the path in which one heavenly body rotates around another. (p. 166)

ore: a mineral containing a metal or metals in combined form. (p. 266)

organ: a group of tissues working together to perform a definite function or work as the heart or the lungs. (p. 509)

organic (or gan'ik) **matter:** compounds containing carbon produced by plants and animals; many organic compounds are now produced by chemical processes and not by plants or animals. (p. 73)

organism: any plant or animal of whatever size. (p. 509)

osmosis (os mo'sis): diffusion of two liquids or gases separated by a semipermeable membrane which permits one of the liquids or gases to pass through it; liquids, gases, and dissolved substances enter and leave cells by osmosis; in each case the cell membrane is the semipermeable membrane. (p. 518)

ovary (o' va ri): flowers, the large part of the pistil in which seeds are formed. Animals, the female reproductive gland which produces egg cells. (p. 529)

ovule (o'vul): the structure, in the ovary of flowers, which surrounds and contains the egg cell. (p. 529)

oxidation (ox i da′shun): the union of a substance with oxygen giving off heat. (p. 46)

oxide (ox′ide): the product formed when oxygen unites with an element. (p. 259)

oxidize (ox′i dize): to unite with oxygen. (p. 49)

pancreas (pan′kre as): a gland which produces digestive enzymes. (p. 634)

parallel (par′a lel): an imaginary line which extends around the earth parallel to the equator. (p. 197)

paramecium (par a me′sheum): a one-celled animal. (p. 573)

parasite (par′a site): organism that takes its food supply from another organism and gives nothing in return. (p. 552)

partial vacuum (par′shal vak′u um): an enclosed space from which most of the air has been removed. (p. 24)

pasteurization (pas′ter i za shun): heating of milk for retarding the multiplication of bacteria in milk. (p. 623)

penumbra (pe num′bra): the lighter part of a shadow which is outside and surrounds the darker part. (p. 392)

petroleum (pe tro′le um): crude oil; a mixture of hydrocarbons taken from the earth. (p. 346)

phases (fa′ses): changes in the appearance of the moon as it moves in its orbit around the earth. (p. 175)

photosynthesis (fo to sin′the sis): chemical process by which the energy of sunlight is stored in carbohydrates which chlorophyll bodies make from carbon dioxide and water in the presence of sunlight. (p. 514)

physical (fiz′i kl) **change**: a change in a substance which does not change its composition. (p. 252)

pitch: the highness or lowness of a tone. (p. 59) The distance between the threads of a screw. (p. 327)

planet (plan′et): one of the nine heavenly bodies rotating about the sun. (p. 166)

planetoid (plan′e toid): one of the group of small bodies whose orbits lie between Mars and Jupiter. (p. 173)

plasma: clear fluid in the blood. (p. 636)

plate: in a radio tube, the piece of metal which receives the electrons discharged from the filament. (p. 487)

pole: the point farthest north or farthest south on the earth's surface; one of two places on a magnet where the magnetism is concentrated, (p. 440); one of the two terminals of an electric cell. (p. 434)

pollen (pol′en): the small grains on the anther of a flower in which the male cells develop. (p. 528)

pollination (pol i na′shun): transfer of pollen from anther to pistil of the same flower or different flowers of the same species. (p. 529)

potential (po ten′shal) **energy**: energy which a body has on account of its position; energy of water held back by a dam; or energy possessed by a spring. (p. 281)

power (pow′er): the rate of doing work. (p. 314)

precipitation (pre sip i ta′shun): the condensation of water vapor into mist, rain, snow, hail, and sleet. (p. 135)

prime meridian: the meridian which passes through Greenwich. (p. 198)
protein (pro′te in): class of extremely complex substances necessary in the food of all plant and animal life; about one sixteenth of protein is nitrogen. (p. 515)
proton (pro′ton): one of the parts of the nucleus of an atom which has a positive electric charge. (p. 255)
protoplasm (pro′to plaz m): living matter in plant cells, (p. 239); animal cells. (p. 508)
protozoa (pro to zo′a): the simplest group of animals; the group of one-celled animals. (p. 571)

quarantine (kwar′an teen): isolation of a person ill with a contagious disease; restriction which attempts to prevent the spread of insect pests. (p. 676)

rayon: a silklike fabric which is manufactured from cells of plants. (p. 544)
red corpuscle (kor′pus l): the red disk-shaped cells in the blood which carry oxygen to the body cells and carbon dioxide back to the lungs. (p. 636)
reflex (re′flex): an action such as winking which is carried on without thought. (p. 644)
reforestation (re for′es ta shun): the planting of trees in areas which were once wooded. (p. 244)
refraction (re frak′shun): the bending of a ray of light when the light passes from one transparent substance into another of different density. (p. 411)
relative humidity: ratio of water vapor in air at a given temperature to the amount of vapor necessary to saturate the air at that temperature. (p. 127)
reproduction (re pro duk′shun): one of the life processes of plants and animals; the production of new life. (p. 508)
reptile (rep′til): a certain kind of vertebrate animals which includes snakes, lizards, and alligators. (p. 592)
resistance (re zis′tance): the opposition to the flow of an electric current through a conductor. (p. 465)
respiration (res′pi ra′shun): breathing; includes inhalation, oxidation, and exhalation. (p. 641)
retina (ret′i na): inside layer of the back chamber of the eye; sensitive layer containing the endings of the optic nerve. (p. 420)
root cap: end of a growing root. (p. 516)

salt: a compound which is formed by the interaction of a base and an acid. (p. 264)
saprophyte (sap′ro fit): organism which gets its food from dead or decaying organic matter. (p. 552)
secretion (se kre′shun): substance manufactured by a gland to do some special work in the body. (p. 642)
sedimentary (sed i men′tary) **rocks:** rocks formed by pressure under water from deposits formed by erosion. (p. 207)
seismograph (sice′mo graf): an instrument to indicate the passing of earthquake waves. (p. 226)
septic (sep′tik): decay produced by action of certain kinds of bacteria. (p. 79)
serum (se′rum): plasma or liquid part of the blood. (p. 677)

short circuit: the flow of an electric current through a shorter circuit than the one it was intended to take. (p. 458)
siphon (si′fon): a tube through which a liquid is forced from a higher to a lower level by air pressure. (p. 29)
skeleton (skel′e ton): the supporting frame of bones inside the body of a vertebrate animal. (p. 588)
sleet: frozen drops of rain. (p. 136)
solar spectrum: band of colors seen when a ray of sunlight passes through a prism. (p. 416)
solar system: the sun and all the planets with their satellites. (p. 156)
soluble (sol′u bl): a substance that will dissolve. (p. 89)
solute (sol ute′): a substance dissolved. (p. 89)
solution (so lu′shun): a liquid in which a solid or a gas has dissolved. (p. 89)
solvent (sol′vent): a substance which will dissolve another substance. (p. 89)
specific gravity (spe sif′ik grav′i ty): the ratio of the weight of a substance to the weight of an equal volume of water. (p. 110)
spore: the reproduction body of a nonflowering plant capable of developing into a new organism. (p. 549)
stalactite (sta lack′tite): an icicle-like deposit of limestone hanging from the roof of a cave. (p. 221)
stalagmite (sta lag′mite): a deposit of limestone built up on the floor of a cave. (p. 221)
stamen (sta′men): male reproductive organ in flowers which produces pollen. (p. 528)
stegomyia (ste gom′a ya): mosquito that carries yellow fever. (p. 671)
stimulant (stim′u lant): a substance which produces an increase in the activity of the organs and other parts of the body. (p. 664)
stomata (stom′a ta): tiny openings in the epidermis of a leaf. (p. 513)
stratosphere (stra′to sfere): the upper of the two layers of the atmosphere. (p. 13)
stratus (stra′tus) **cloud:** sheet-like cloud sometimes in long, narrow bands. (p. 133)
streamlined (stream′lined): a body designed to decrease air resistance. (p. 331)
sunspot: a dark spot caused by a violent eruption of gases on the surface of the sun. (p. 163)
suspension: a mixture of a liquid and particles which do not dissolve. (p. 89)

temperature (tem′per a chur): the measure of the intensity of heat. (p. 355)
testa (tes′ta): skin of a seed. (p. 533)
textiles (tex′tils): fabrics woven from materials such as cotton or wool. (p. 542)
theory (the′o ri): a proposed explanation based on experiment. (p. 2)
thermostat (thur′mo stat): an automatic device for regulating temperature. (p. 361)
tides: the rise of water on large bodies of water due to the attraction of the moon and sun. (p. 177)
timbre (tim′ber): the quality of a tone. (p. 60)
tincture (tink′chur): a solution in which alcohol is the solvent. (p. 89)

tornado (tor na′do): a funnel-shaped, violently whirling, and very destructive wind. (p. 147)

toxin (tox′in): a poison produced by disease germs. (p. 676)

transformer (trans form′er): an apparatus for increasing or decreasing the voltage of an alternating current in a circuit. (p. 451)

translucent (trans lu′sent): a substance which allows some light to pass through it but which is not transparent. (p. 392)

transparent (trans par′ent): a substance which allows light to pass through it so that an object can be clearly seen. (p. 392)

troposphere: the lower of the two layers of the atmosphere; the one next to the earth. (p. 13)

tuber: underground stem. (p. 539)

tungsten (tung′sten): a metal used for filaments in electric lamps. (p. 399)

umbra (um′bra): the dark part of a shadow which received no direct light from a source of light. (p. 392)

vaccination (vak si na′shun): the production of a mild form of a disease in an animal by the use of weakened or dead germs or the product from the germs. (p. 675)

vaccine (vak′sin): a substance used in inoculations or vaccinations. (p. 676)

vacuum (vak′u um): a space which contains no matter. (p. 16)

vaporize (va′por ize): changing of a solid or liquid to vapor. (p. 90)

vegetative reproduction: the growing of plants without the use of seeds. (p. 525)

veins: the system of blood vessels through which blood returns from the capillaries to the heart. (p. 638)

vertebrates (ver te brates): the kinds of animals which have an inside skeleton, part of which is a backbone. (p. 588)

villi (vil′i): tiny projections in the mucous membrane of the small intestine, contains lacteals and capillaries. (p. 635)

vitamins (vi′ta mins): food substances essential to health, growth, and development. (p. 617)

volt: the unit of electrical pressure. (p. 437)

watt (wot): the unit of electric power; ampere x volt. (p. 456)

wave frequency: number of waves passing a given point per second. (p. 54)

weathering: changes in rock formations due to heat, rain, rivers, wind and waves. (p. 214)

work: the act of moving a weight or overcoming resistance. (p. 312)

X-rays: short electromagnetic waves that have great penetrating power. (p. 404)

yeast: a fungus plant consisting of one cell; when put into a dilute sugar solution, it breaks up the sugar and sets carbon dioxide free; causes dough to rise. (p. 559)

INDEX

Abdomen, of insects, 582–583; of the body, 633
Accidents, on highways, Fig. 1; prevention from electricity, 474–475; prevention of, in homes, 400
Acetylene, 88; welding, 88
Acid, 260; acetic, 261–262; citric, 261; hydrochloric, 261, 264; lactic, 261; organic, 261–262; properties of, 260; sulfuric, 43; wastes in soil, 242, 272–273
Acre foot, 237
Adhesion, 287
Adulteration of foods, 669
Agriculture, 228–247
Air, 10–49; compressed, 32–37; exerts pressure, 14–32; in porous materials, 11; in soil, 229; in water, 12; medium of transportation, 10–11, 19–22; weight of, 13–14
Air brakes, operation of, 32–33
Air pressure, how measured, 15–19; in drinking, 25; in filling medicine dropper and fountain pen, 31–32; in operating siphon, 29–30; in operation of vacuum cleaner, 30–31; in partial vacuum, 24–25; lift on airplane wing, 22; operation of pumps, 26–29
Air-conditioning, 97; of homes, factories, and public buildings, 380–382
Airplane, 8, 10; altitude records, 12–13; first flight of, 20
Airship, 20–21; travel by, 22, 268
Alchemists, 6
Alcohol, 76, 261–262; wood, 343, 547; effect on the body, 665–667
Algae, 549–551
Alkalies, 262–263
Alloys, 259, 267–271
Alternating current, 451
Altimeter, 19
Altitude, effect on air pressure, 17–18; effect on climate, 122
Aluminum, 259; oxide, 259–260, 266–268
Ammeter, 436
Ammonia, nitrogen in, 75, 96–97, 260, 401; products from coal, 345
Ammonium, chloride, 435–436; hydroxide, 264
Amoeba, 509, 572–573
Ampere, 436; experiments with electricity, 5, 436, 456
Amphibians, 590–591
Anaesthetics, 260
Anemometer, 138
Aneroid barometer, 18–19
Animals, amoeba, 572–573; amphibians, 590–591; birds, 593–595; burrowing, 229, 569, 605; classification of, 570–571; coral, 575; deposits of, 212, 216; differ from plants, 570; hydra, 576–578; insects, 581–586; invertebrates, 575–588; mammals, 595–597; mollusks, 586–588; paramecium, 573–574; pests, 563–564; prehistoric, 208; protozoa, 571–574; raw materials from, 597–601; reptiles, 592–593; spiders, 585–586; sponges, 575; vertebrates, 588–597; worms, 578–580
Annual rings, 521–523
Anopheles mosquitoes, and malaria, 671
Antennae, of insects, 582; radio, 490, 492
Anthracite coal, 340
Anthrax, 664
Anticyclones, 143–144
Antiseptics, 661–662; experiment with, 662
Antitoxin, 676
Ants, 216, 585
Anvil, ear, 64
Aorta, 638
Archimedes, 105; principle of, 105
Arcturus, 182
Argon, in air, 40; use of, 40
Armature, of generator, 450–451; of motor, 463
Arms, of lever, 318–322
Arteries, 638–640

Artesian well, 219–220
Arthropods, 581–586
Artificial light, 164; candles used for, 393–394; early use of, 386; electricity used for, 398–401; gas used for, 395–396; kerosene used for, 394–395; modern use of, 393
Artificial silk, 544
Aseptic surgery, 662
Assimilation, 635
Astigmatism, 423
Astronomers, beliefs of early, 3–5, 156, 161, 167, 169, 172, 173, 175, 181, 188
Astronomy, 156–204; beginnings of, 156; comets, 187–188; longitude and latitude, 197–201; meteors, 12, 17, 188; seasons, 194–197; the earth, 190–194; the moon, 174–180; the planets, 166–174; the stars, 181–187; the sun, 157–166
Atmosphere, 11; change in pressure due to altitude, 17–18; composition of, 38–44; exerts pressure, 14–15; height above earth's surface, 12, 17; how measured, 15–19
Atoms, 254–255; structure of, 428–429
Auditory, canal, 64; nerve, 65
Axis, 192–197

Babbitt metal, 267
Bacilli, 655–657
Bacteria, 79; nitrogen fixation, 240, 261, 659; preventing growth of, 264, 654–664; culture of, 657; forms of, 655–657; growth of, 657, 660; harmful, 658; illustrations of, 656; in decay of matter, 659; in milk, 658–659; reproduction of, 657; useful, 658–659; effect of sunlight on, 660
Baking powder, 42, 266
Baking soda, 42; use in fire extinguisher, 43, 266
Balloon, stratosphere, 12, 13, 17
Barograph, 19
Barometer, 15; construction of, 15–16; kinds of, 15–19; use of, 15, 268
Bases, alkalies, 262; properties of, 262; useful to men, 263–264
Bathysphere, 36–37
Batteries, storage, 267, 471–473
Bearings, 330
Bees, honey, 584–585
Bell, Alexander Graham, 482
Beri-beri, 619
Bessemer converter, 270
Big dipper, 185–186
Bile, 634
Biology, 574
Birds, 593–595; characteristics of, 595; economic value of, 593–595; food of, 593; migration of, 593; nesting habits, 593
Bituminous coal, 340
Blast furnace, 269–270
Bleaching powder, 260–261, 273
Bleeding, 639
Blood, 636–640; circulation, 637–640; clotting, 638; color of, 638; corpuscles, 636; food carrier, 636; plasma, 636–637; pressure, 640; transfusion, 640
Blood pressure, 640
Blood transfusion, 640
Body, compared to machines, 606; composition of, 507–508; human, 250
Boiler scale, 97
Boiling point, 366–368
Bones, and Vitamin D, 620–621
Bottle, Vacuum, 373–374
Brain 645–648; cross section of, 646; parts of, 646–648
Brass, 267
Breathing, 640–642
Broadcasting station, 491
Broadcasting studio, 491–492
Bronchi, 640
Bronze, 267; Age of, 317
Budding, 525–527
Buds, 512; terminal, 522
Buoyant force, 105
Burbank, Luther, 538
Burning (see combustion)
Butter, 261, 611, 613

Caisson, operation and use of, 34–36
Calcium, and Vitamin D, 621; compounds in water, 75–76; hydroxide, 262, 264; in building materials, 270–275; in foods, 615–616; in plant growth, 237–242; oxides, 259, 260
Calendar, Babylonian, 3; early Egyptian, 3; Gregorian, 191–192; Roman, 191
Calorie, 359, 365; food values, 614–615; in daily diet, 615
Calyx, 528
Cambium, 521, 526–527
Camera, 172; film of, 413–414; lens of, 413–414; motion picture, 415–416; pinhole, 391

Candle, 259, 349, 394
Candle power, 388–390
Capillaries, regulated by magnesium, 616, 638–640
Capillarity, 288–289
Carbohydrates, 238; test for, 613
Carbolic acid, 345
Carbon, and oxygen cycle, 41; as a constituent of fuels, 338–351; as plant food, 237–238; in fuels, 45; number of compounds containing, 257, 259, 270–271
Carbon dioxide, exhaled in breathing, 41; from burning kerosene, 395, 514; in air, 38–47; in weathering, 41; making of dry ice, 42; product of burning fuels, 349–350; test for, 40
Carbon monoxide, 349–350
Carboniferous Age, 339–341
Carburetor, 302
Carrier pigeons, 478
Cast iron, 270
Caterpillar, 583
Caustic soda, 263–264, 601
Caves, natural, 220–222
Cell division, of amoeba, 573; of plant, 510, 522, 530, 657
Cellophane, 544–545
Cells, 508; division of, 509–510, 522; egg of hydra, 578; egg of plants, 530; electric, 433–436; nerve, 576, 644–648; plant, 507–510; sperm of hydra, 578; sperm of plants, 530; structure of, 509
Celluloid, 543
Cellulose, 545
Cement, 272
Centigrade, thermometer, 355–359
Centrifugal force, 284
Centimeter, 313
Cerebellum, 646–647
Cerebrum, 646–647
Chalk, 213; cliffs, 571
Charcoal, 342, 343
Chemical action, 216; electricity produced by, 434–436; heat produced by, 353; produced by light, 413
Chemical change, 252–253, 419
Chlorine, 75, 261
Chlorophyll, 513–515
Chlorophyll bodies, 655
Chloroplasts, 514
Cholera, 72
Choroid, 420
Chromium, steel, 271
Chromosphere, 163
Chyme, 634
Cilia, of paramecium, 574
Circuits, antennae, 490; electrical, 433–439; filament, grid and plate, 489
Circulation, of air in homes, 376; of air in refrigerator, 366; of blood, 636–640; of water, in heating system, 378; of water, in hot water heater, 371
Circulatory system, of amphibians, 591; of earthworm, 580; of fish, 589; of insects, 583; of man, 636–640; of reptiles, 592
Cirrus, 133
Clay, soils, 229–231
Climate, 116; effect of altitude on, 122; effect of land and sea breezes, 124, 209; in arctic regions, 120–121; in temperate regions, 121–122; in tropics, 120
Clothing, 9; artificial and natural silk, 544, 569; destroyed by moths, 582; affected by weather, 118, 419; from cotton, 542–543; from linen, 543–544; from wool, 599; furs, 600; leather, 600
Clotting, of blood, 638
Clouds, 129–134; formation, 129–132; kinds of, 17, 132–134
Coagulation, 546
Coal, anthracite, 340, 344; as fuel, 338–351; bituminous, 339–340, 344; formation of, 208, 213, 214, 339–340
Coal gas, 344
Coal tar, 345
Cocoon, 583
Cod liver oil, 617–621
Codling moth, 563
Coffee, 664–665
Cohesion, 286–287
Coke, 269; manufacture of, 344–346
Colds, 674
Collodion, 543
Color, 386, 416–419; rainbow, 416–418; spectrum, 416–419
Combustion, 45; products of, 45, 338–351
Comets, 187–188
Communication, affected by weather, 119; by electricity, 478–497; radio, 5, 8, 485–497; telegraph and telephone, 5, 480–485
Commutator, 463
Compass, 434, 442–443, 447
Compounds, 257, 259–266; acids, 260–262; bases, 262–264; oxides, 259–260; salts, 264–266
Concave lens, 412

Concrete, 272
Condensation, 44, 90
Conduction, of heat, 369–370
Conductors, of electricity, 429; of heat, 369–370; of sound, 56
Conservation, of energy, 283; of matter, 253; soil, 237–245
Constellations, 184–185; big dipper, 185; cassiopeia, 185; orion, 185; southern cross, 185
Contamination, 675
Convection, 370–381; currents, 371; hot water heater, 371–372
Convex lens, 412–416, 419–423
Cooking food, 627
Copernicus, 5
Copper, 266–267; in foods, 615–616, 628; refining of, 471
Coral, 575–576
Cork, 521, 524, 546
Corn borer, 582
Cornea, 420
Corolla, 528
Corona, 163
Cortex, 516
Cosmetics, 260
Cotton, 542–543; oil from seed, 543
Cotton boll weevil, 564
Cotyledons, 533–535; dicotyledons, 534–535; monocotyledons, 534–535
Cow-pox, relation to smallpox, 7
Crabs, 581
Crank shaft, 302
Crater, 223
Crops, 231; in Nile valley, 235
Crystal radio set, 493–494
Culex mosquito, 671
Cumulus, 133
Cyanamide, as fertilizer, 238
Cylinder, in gasoline engine, 302–303; in steam engine, 298
Cyclones, 141–143

Decay, bacteria of, 659
Defective vision, 422–423; astigmatism, 423; correction of, 423; far-sighted, 423; near-sighted, 423
Dendrites, 644
Density, 107–110; of planets, 167
Developer, 415
Dew, 129
Diaphragm, phonograph, 61; telephone, 483
Dicotyledon, 534
Diet, balanced, 610–616
Diffusion, of light, 410
Digestion, in hydra, 577; in a stomach, 630–635
Digestive system, of earthworm, 579–580; of hydra, 577
Dinosaurs, 569
Dipping needle, 442
Diphtheria, 676
Direct current, 451
Direct lighting, 400–401
Diseases, carried by protozoa, 571; germs in water, 71–72; of prehistoric man, 658; protection from, 654–667
Disease germs, carried by animals, 663; in water, 71–75; protection from, 659–667; protection of food from, 662; resistance to, 663–664; unfavorable conditions for, 660
Disinfectant, 273
Disinfection, 678
Distillation, of petroleum, 347–348; of water, 91
Diving suit, 36–37
Doldrums, 140
Doorbell, 479–480
Drainage, 233–234
Drugs, 261–547; effect on the body, 664–667
Dry cell, 435–436
Dry ice, 42, 251
Duraluminum, 268
Dust storms, 244
Dyes, 261, 263, 345, 547, 598

Ear, human, 63–65
Ear drum (tympanic membrane), 64
Earth, 174, 190–201; crust, 207–227; gravitation of, 290; imaginary lines on, 197–198; inclination of axis, 194–196; motions of, 190–192; shape of, 192–194
Earthquakes, 224–226
Earthworm, 216, 579–580
Earth's axis, inclination of, 194
Earth's crust, action of plants and animals, 216; action of water, 217–219; changing today, 209; effect of glaciers, 216–217; formation of, 207
Echoes, 56–57
Eclipses, 177–178, 392; of moon, 177; of sun, 178, 392
Edison, Thomas, 399
Efficiency of machines, 329
Eggs, of chicken, 595; of frogs, 590–591; of insects, 583

Elasticity, 287–288
Electric, arc, 164, 468–469; bell, experiment with, 361; circuit, 361; current, 361; signs, 399
Electric charges, 428–433
Electric circuits, 433–439; in parallel, 438–439; in series, 437–438
Electric lighting, 396–401; fixtures for, 399–401; tungsten lamp, 398
Electric locomotive, 499–500
Electricity, 249, 255, 278, 280, 293–296, 427–505; charges, 429–433; communication and transportation by, 478–505; conductors of, 429; doorbell, 479–480; dry cell, 435–436; electric currents, 433–439; electroplating, 470–471; electrotyping, 471; for lighting, 396–402; fuses, 458–459; generators, 449–451; heat produced by, 353, 465–469; injuries from, 474–476; locomotive, 499–500; magnetism, 439–449; meters, 455–458; motors, 462–465; Ohm's law, 437; on ships, 500–501; on steam trains, 499–500; radio, 485–497; series and parallel circuits, 437–439; storage battery, 471–473; streetcar, 497–498; telegraph, 480–482; telephone, 482–485; theory of, 428–429; transformers, 451–455; uses of, 461; voltaic cell, 433–435; with gas motors, 498–499; X-rays, 473–474
Electrodes, 434
Electrolysis, of water, 84–85
Electrolyte, 434, 470
Electromagnetic waves, 405, 485–487
Electromagnets, 448–449, 463, 479–483
Electrons, 255, 428–433, 487–489
Electroplating, 470–471
Electrotyping, 471
Elements, 254–256; composition of, 254–255; discovery of, 255–256; how classified, 255–256; necessary for plant growth, 515; table of symbols, 256
Embryo, 530–531
Energy, 164–166; changed from one form to another, 280–283; conservation of, 280, 283; from foods, 606–616; kinetic, 281; potential, 281; related to matter, 249–275; sun a source of, 280–283
Engine, gasoline, 302; steam, 298
Environment, 1
Enzymes, 633
Epidemic, caused by impure water, 71–72
Epidermis, of leaf, 512–513; of root, 516–521
Equator, 197
Erosion, 217–219, 518–520
Esophagus, 632
Ether waves, 403–405
Eustachian tube, 64
Evaporation, 43, 91–97, 165, 231
Exercise, effect on body, 679–680
Exhaust pump, use of, 14
Expansion joint, 360–361
Experimentation, by early man, 1; question answered by, 7–8
Explosives, 40, 240, 261, 285, 345
Eye, care of, 399–402; correction of defects, 422–423; defects, 422–423; human, 419–423; parts of, 420–421; seeing, 421–423

Fahrenheit, thermometer, 355–359
Falling bodies, 291
Faraday, experiments with electricity, 5
Fats, 612; test for, 612
Fault, 224–225
Fermentation, 261
Ferns, 549
Fertilization, in flowers, 530
Fertilizers, 237–243, 266; from animal wastes, 601
Fibrin, 638
Filaments, carbon, 398; early experiments with, 398; gills of fish, 589; in radio tube, 487; of flower, 528; tungsten, 398
Film, motion picture, 40
Filter, 73
Filth, disposal of, 659
Filtration, 73–74
Fire, early history of, 336; to produce heat, 336
Fire extinguisher, 43
Fish, 588–590
Fish hatcheries, 590
Flagella, 656
Flame, production of, 348–349
Flies, as carriers of disease, 672; house, 582; life history of, 672–673; protection from, 673
Floating bodies, 105–106
Flood control, 244–245
Flowers, parts of, 528–529; pollination of, 529–530; structure of, 527–529
Focal length, 413

Focus, 412–413, 419–423
Fog, 130
Food, 606–629; adulteration of, 669; and health, 664; cooking of, 627–628; digestion of, 630–635; experiments with, 609; from animals, 601; from fruits, 538–539; from leaves, 537–538; from plants, 537; from roots, 539–540; from stems, 539; government inspection of, 669–670; measurement of values, 614–615; meat, 625; milk, 623–625; minerals in, 615–616; poisons on, 616; preservation of, 669; preserving, 660; protective, 617; sugars, 622–623
Food tables, 627–628
Foot candle, 164, 388
Foot-pound, 313–315
Forces, 102, 209, 228, 278–307; adhesion, 287; capillary attraction, 288–289; centrifugal, 284; cohesion, 286–287; elasticity, 287–288; expanding gases, 284–285; inertia, 283; molecular, 285–289
Forest fires, 563
Fossils, 208, 213
Franklin's experiment, 431-432
Freezing, point of water, 356; effect on some substances, 364–365; point of mercury, 358
Frequency, 54
Friction, 329–331; and lubrication, 330–331; heat produced by, 351–352, 431
Frogs, life history of, 590–591
Frost, 129
Fruits, acids, 261; and Vitamin C, 619–620; as foods, 538–539
Fuels, 338–348; formation of, 338–342; kinds of, 338–351; used today, 338
Fulcrum, 318–322
Fumigation, 678
Fungi, 552–561
Furnaces, blast, 269–270; electric arc, 467–468; for heating homes, 375–380; for manufacturing glass, 273; open-hearth, 270–271
Fur, 600
Fuses, 458–459
Fusion, 364

Galileo, early discoveries about solar system, 5; laws of pendulum, 5, 26, 171, 291
Galvanized iron, 267
Galvanometer, 449, 452
Garbage, disposal of, 659, 673
Gas, 249–250, 339, 346; artificial and natural for lighting, 395–396; effect of heat on, 363–364; formation of, 340–341; from wood, 342; necessary for flame, 348–349
Gas masks, 343
Gaseous, 159
Gasoline, 251, 302–304, 347–348
Gasoline engine, parts of, 302–303; principle of, 301–304
Gastric juice, 261, 264, 633
Generator, alternating and direct, 451; electrical, 449–451; essential parts of, 450; principle of, 450
Germination, 532
Germs, disease, 658–659
Geysers, 226–278
Glaciers, 208, 216–217, 228
Glands, 631, 634, 642–643; ductless, 642; hormones, 642–634
Glass, 273–275; glass blowing, 273–274; history of, 274–275; plate, 274; window, 273; safety, 275
Glucose, 614
Glue, 600–601
Glycogen, 614
Goiter, 616, 643
Grafting, 525–527
Gram-centimeter, 313–314
Grand canyon, 209, 218
Gravity, 279, 290–291, 293–296
Greenwich, 149, 198
Grid, in radio tube, 488–489
Guard cells, 513
Gunpowder, nitrogen in, 40
Gypsy moth, 563

Habits, 644–649
Hail, 144, 149
Halley's comet, 187–188
Health, 606–683; benefits of, 607; care of foods, 660; care of teeth, 631–632, 663; choice of, 607–609; effect of blood circulation, 637, 639; effect of food on, 607–609; effects of alcohol and stimulants on, 664–666; effects of nicotine on, 666–667; endangered by insects, 671–673; habits of cleanliness, 668–669; nature's formula for, 679–681; promoted by governments, 670–671; protection from diseases, 674–678; resistance of the body, 663–664; vitamins and, 617–622
Hearing, 63–65

Heart, 637–640; circulation of blood through, 638; location of, 637; structure of, 637
Heat, 336–385; as a servant of man, 355–382; effect on air, 137, 249, 280; effect on gases, 363–364; effect on liquids, 362; effect on metals, 360–361; from radium, 353; fuels, 338–348; greatest source of, 337; in earth's interior, 353; measurement of, 359; of fusion, 365; of vaporization, 367; produced by chemical action, 353; produced by collision, 353; produced by combustion, 338–351; produced by compression, 352–353; produced by electricity, 353, 465–469; produced by friction, 351–352; transmission of, 369–374; used in cooking, 374
Heat equator, 140
Heating systems, hot air furnace, 376–377; hot water and steam, 377–379; pipeless furnace, 375–376; principle of, 375–379; the stove, 375
Helium, 20, 40, 161, 162, 251, 255
Hemoglobin, 636
Henry, experiments with electricity, 5
Herschel, William, 171–172
Homes, adobe house, 117; effect of weather on, 118; electrical appliances, 461, 466–467; heating of, 374–380; humidity in, 379–380; lighting of, 400–401, 407–408; lumber for building, 540–542, 569; necessity of heat, 338; sunlight in, 387; water system, 77
Hook-worm, 579
Hormones, 642–643
Horse latitudes, 140–141
Horsepower, 315
Humidity, 126–128; in homes, 379–380
Hurricanes, 146
Hybridizing, 538
Hydra, 576–578
Hydraulic press, 103-104
Hydrocarbon, composition of, 346, 395
Hydroelectric power, 294
Hydrogen, 40, 85–88; as plant food, 238, 255, 259, 546; preparation of, 86–87; properties of, 87; uses of, 87–88
Hydrometer, 472–473

Ice, artificial, 97; dry, 42, 251; refrigeration with, 365–366
Igneous rocks, 207, 209, 211
Illumination, 400–401
Images, 390–391
Imaginary lines, 201; equator, 197; meridians, 198; parallels, 197–198; prime meridian, 198
Immunity to disease, 664, 676
Incandescence, 159, 393
Inclined plane, 326–327
Induced currents, experiment on, 449–451
Induced magnetism, experiment on, 443
Inertia, 283
Infectious, 678
Inoculation, 7; and diphtheria, 676
Insects, 581–586
Insulators, 429
Intestines, 634–635; diagram of, 633
Invertebrates, 575
Iodine, in foods, 615–616, 628
Iris, 420
Iron, Age, 269, 317; alloys of, 270–271; as plant food, 238, 250, 259; in food, 615–616; metallurgy of, 269–271; ores of, 269; rusting of, 46, 253
Irrigation, 234–237
Isobars, 149–150
Isotherms, 149–150

Japanese beetle, 563
Jelly-fish, 575
Jenner, Edward, 675; and vaccination, 7, 675–676

Kidneys, 637
Kilowatt, 456–458
Kiln, cement, 272; lime, 272–273
Kindling temperature, 46, 338, 352, 344
Kinetic energy, 281, 295, 364
Kite, and Franklin's experiment, 431–432

Lactose, 614, 622
Lamps, gas filled, 398; gas mantel, 397; incandescent, 398–399; kerosene, 394; tungsten, 399–400
Land breeze, 124
Larva, 583
Larynx, 63
Latex, 546
Latitude, 198
Laughing gas, 260
Lava, 211
Lavoisier, 6, 45
Laws, Ohm's, 437; of electric charges, 430; of gravitation, 5; of intensity of illumination, 388–389; of machines,

Laws—(*Continued*)
318–320; of magnetic poles, 441; of pendulum, 5
Layering, 525, 527
Lead, 266–267
Leap year, 192
Leather, 600
Leaves, 511–515; a food factory, 514–515; arrangement on stem, 512; as food, 537–538; blade and petiole, 511; cross section of, 513; kinds of veining, 511, 512; structure of, 512–514
Leguminous plants, 240
Lenses, 412–413; camera, 413–416; concave, 412; convex, 412; field glass, 413; focal length, 413; focus, 412; magnifying glass, 413; microscope, 413; motion pictures, 415–416; telescope, 413
Lever, 318–322; classes of, 320–322; parts of, 318–319
Lichens, 216
Life history, of frogs, 590–591; of insects, 583
Life processes, of animals, 570–571; of earthworm, 579–580; of hydra, 576–578; of insects, 581–586; of paramecium, 574; of plants, 508
Light, 249, 280, 386–426; artificial, 393–401; diffusion of, 410; from sun, 387–388; human sight, 419–423; intensity of, 388–389; measurement of, 388; motion pictures, 415–416; photography, 413–415; reflection of, 407–410; refraction of, 410–423; shadows, 391–392; solar spectrum, 416–419; spectrum of, 404–405; speed of, 404–407; theory of, 403–404; waves, 404
Light year, 181
Lighting fixtures, electric, 399–401; gas, 396
Lightning, 145, 431–433
Lightning rod, 432–433
Lime, 243, 260, 272–273
Limestone, 212–213, 216, 220–221, 269, 272–273, 340–341
Liquid, 250; effect of heat on, 362–363
Lister, Joseph, 661–662
Litmus paper, 260, 262
Liver, 634
Loam, 229
Lodestone, 439
Longitude, 198
Lubrication, 330–331
Lumber, 540–542; seasoning of, 541–542
Lungs, purifying blood, 638, 640–642
Lye, 264

Machines, 308–333; and work, 310–316; classes of levers, 320–323; defined, 316; development of, 316–317; efficiency of, 329; friction in, 329–330; lubrication of, 330–331; of early man, 308–309; the inclined plane, 326–327; the law of, 319–320; the lever, 318–319; the mechanical advantage of, 321–323; the pulley, 323–324; the screw, 327–328; the simple, 317–328; the wedge, 328; the wheel and axle, 324–325
Magnesium, as plant food, 237; compounds in water, 75–76, 259; in foods, 615–616
Magnetic field, 445
Magnetism, 439–449; experiments on, 443–445; induced, 443; magnetic field, 445; nature of, 445–446
Magnets, 439–449; artificial, 439–441; bar, 440–441; electromagnets, 446–449; the earth as a, 441–442
Malaria, carried by mosquito, 7, 571, 671
Maltose, 622
Mammals, characteristics, of, 595–596
Marble, 214, 272
Mars, 169–170
Marsh gas, 346
Matches, manufacture of, 352
Matter, 248–277; changes of, 251–253; composition of, 254–259, 507–508; conservation of, 253; differs from nonliving, 508; living, 507–510; related to energy, 249–250; states of, 250–251; structure of, 508–510
McCollum, E. V., 609–610
Meat, 9, 625
Mechanical advantage, 321–323
Medulla, 646–647
Medullary rays, 522
Melting, point of substances, 364
Membrane, 641
Mercury, freezing point of, 359; metal, 251, 266–268, 289; planet, 168–169
Mercury manometer, 640
Meridians, 198
Metallurgy, 267
Metals, 266–272; alloys, 259; conductivity of, 266; effect of heat on, 360–361; fusibility of, 266; luster of, 266; malleability of, 266; ores of, 266–267

Metamorphic rocks, 207–208, 213–214
Metamorphosis, 582–585
Meteorite, 188
Meteors, 12, 188
Meters, electric, 456–458; water, 81–82
Microbes, 654
Microphone, 490
Microscope, lenses of, 413; use of, 228–229
Milk, certified, 624–625; pasteurization of, 623–624, 623–625; souring of, 252–253, 658
Minerals, in foods, 537, 615–616; table of, in foods, 628; test for, 615, 622–623
Mixture, 258–259, 266
Molds, 553–556
Molecular activity, 257–258; effect of heat, 364; in osmosis, 517–518
Molecular forces, 285–289; adhesion, 287; capillarity, 288–289; cohesion, 286–287; elasticity, 287–288
Molecules, 257–258; activity, 257–258; motion of, 258, 285–289; size of, 257
Mollusks, 586–588
Monel metal, 267
Moon, 174–180; eclipse of, 177; phases of, 175–176; surface of, 174; tides caused by, 177–180
Morse, Samuel F. B., 480
Mosquitoes, kinds of, 671; life history of, 671–672
Mosses, 549
Moths, clothing, 582; silk, 598
Motion pictures, 62–63, 415–416
Motor, construction of, 462–463; electrical, 5, 461–465; essential parts of, 463; principle of, 463; uses of, 464–465
Mouth, digestion in, 631
Muscle Shoals, 240–241, 294, 455
Musical instruments, 59–61

Natural gas, as fuel, 346
Neap tides, 180
Nebula, 183
Negative charges, 429–433
Neon, in air, 40; use of, 40, 398
Neptune, 172
Nerve, 644–649; auditory, 65; cells, 644–648; motor, 646; optic, 420; sensory, 646
Nervous system, 644–649; brain, 646–648; habits, 649; memory, 648–649; nerve messages, 648; network of, 644–645; of earthworm, 580; of fish, 589–590; of hydra, 576–577; of insects, 583; spinal cord, 645
Neurones, 644–645
Neutralization, 264
Newton, discovery of laws of gravitation, 5, 283; theory of light, 403–404
Nicotine, 666
Nitrocellulose, 543
Nitrogen, in air, 38–40; in plants, 238–241; uses of, 40
Nitro-glycerin, nitrogen in, 40, 261
Nitrous oxide, 260
Node, 512
Noise, 65
Nonconductor, 429
North star, 182–186
Northern lights, 443
Nucleus, of atom, 255; of plant cell, 508

Observation, aid to discoveries, 2–3, 219
Ocean currents, effect on climate, 122
Oersted, experiments with electricity, 5
Ohm, 437
Opaque, 392
Open hearth, 271
Optic nerve, 420
Orbit, 166, 284
Ores, 266–267
Organic, as fertilizer, 240; in soil, 228–229; matter in water, 73
Organism, 509
Organs, 509
Osmosis, and root hairs, 518; experiment on, 517–518; in respiration of fish, 589
Ovary, of flowers, 528–529
Ovules, of flowers, 528–529
Oxidation, examples of, 46–47
Oxide, 259–260; useful to man, 259–260
Oxygen, 38; as plant food, 238, 250–251; by-product of photosynthesis, 514–515; carried by blood, 638; discovery of, 6; in burning, 44–47; preparation of, 44; test for, 39, 44
Oxyhydrogen blowtorch, 88
Oysters, enemies of, 578, 586; food of, 571

Paints, 260, 267, 345
Pancreas, 634
Paper, 263; manufacture of, 545
Paraffin, 348–394
Parallels, 197–198
Paramecium, 509, 573–574

Parasites, 552; worms, 578–579
Pascal, 3, 18, 103
Pasteur, treatment for rabbis, 7
Pasteurization, 623–624
Pelton wheel, 295
Pendulum, discovery of laws of, 5; experiment with, 282
Penumbra, 392
Petal, 528
Petiole, 511
Petroleum, 264; as fuel, 346–347; formation of, 340–341; refining of, 347–348
Phases of moon, 175–176
Phenomenon, 2
Phonograph, 61–62
Phosphorous, 39; as plant food, 238, 241–242, 259; in foods, 615–616
Photography, 413–415; developer, 414–415; silver compounds used, 413–414
Photosynthesis, 514–515
Physical change, 252
Pistil, 528
Piston, of gas engine, 302–304; of steam engine, 298–299
Pitch, music, 59; screw, 327
Planetoids, 173–174
Planets, 5, 166–174; markings on, 167; orbits of, 166; table of, 168; weight of, 167–168
Plant cells, 508–510
Plants, 116–117, 165, 208, 216; algae, 549–551; animal pests of, 563–564; cellophane, 544–545; classification of, 534–535; cotton, 542–543; fertilization, 530; flowers, 527–529; food from, 537–540; forest fires, 563; fungi and plant diseases, 552–561; gigantic, 339; grafting, layering, and budding, 525–527; green store up energy, 280, 339; leaves of, 511–515; lint, 543–544; lumber, 540–542; mosses and ferns, 561; paper, 545–546; promoting growth with electricity, 468, 506–568; requirements for growth, 228–244; roots, 515–520; rubber, 546 (new); seeds, 530–534; silk, 544; stems, 520–525; structure, 507–510; weeds, 561–563
Plasma, 636
Plaster, 260, 273
Plate, in radio tube, 487
Pleura, 641
Pleurisy, 641
Pneumatic, tools, 34
Poisons, in foods, 616
Pole, 434
Pollen, 528–530
Pollination, 529–530
Positive charges, 429–433
Potassium, as plant food, 238, 242–243, 259; hydroxide, 262, 264
Potential energy, 281, 295
Power, 314–315; horse, 315; measurement of electrical, 455–458
Precipitation, 135
Preservative, 669
Preserving food, 660
Pressure, air, 13–22; electrical, 437; water, 99–104
Priestley, discovery of oxygen, 6; explained burning, 44
Prime meridian, 198
Prism, 416–419; experiment with, 417–418
Protective foods, 617
Proteins, 237, 515; elements in, 515; test for, 610, 610–612
Proton, 255, 429
Protoplasm, 239, 508, 572–573
Protozoa, 571–574, 654–660; amoeba, 572–573; paramecium, 573–574
Ptolemy, 4
Public address systems, 496–497
Pulley, 323–324; experiment with, 324
Pump, exhaust, 14; force, 28–29; lift, 26–28
Pupa, 583
Pupil, 420
Pure Food and Drug Act, 669–671
Pylorus, 633
Pythagoras, 4–5

Quality, of musical tones, 60
Quarantine, 676–678

Radiation, of heat, 372–373
Radio, 5, 8, 485–497; alternating current receivers, 495, 496; battery receiving set, 494; crystal receiving set, 493–494; public address systems, 496–497; tubes, 487–490; tuning, 494–495; waves, 487, 490–491; tubes, 487–489
Radio waves, 487; carrier, 490, 489–490, 494
Radio-active substances, heat porduced by, 353
Radiometer, illustration of, 372
Radiophone, 486

Rain, 134–136, 209, 215
Rain gauge, 136–137
Rainbow, 386
Rainfall, 134–137; hail, 136; how measured, 136–137; rain, 134–136; sleet, 136; snow, 135, 228–229
Rare gases, in atmosphere, 40
Rayon, 544
Recreation, and weather, 119–120
Red corpuscles, 636
Reflex actions, 644
Reforestation, 244
Refraction of light, 410–423; cause of, 411–412; experiment on, 410–411; images, 413–416; in glass, 411–419; in human eye, 419–423; in lenses, 412–416; in prisms, 416–419; in water, 410–411
Refrigeration, 94–97; diagram of ice refrigerator, 366; with ice, 364–365
Relative humidity, 127–128
Rennin, 633–634
Reproduction, of amphibian, 590–591; of bacteria, 657; of earthworm, 580; of fish, 590; of honeybee, 584–585; of hydra, 578; of insects, 583; of mammals, 592; of protozoa, 572–574; of reptiles and birds, 592; one-celled plants, 550; vegetative, 525–527
Reptiles, 592–593
Resistance, air, 331–332; and Vitamin A, 618; and work, 312–313; electrical, 437, 465–468; to disease, 663–664
Respiration, of amoeba, 573; of earthworm, 579; of fish, 588–589; of frogs, 591; of humans, 641–642; of insects, 582
Retina, 420
Rickets, 620–621
Rivers, 219; systems, 230
Rocks, 207–214; book of the past, 208; igneous, 207, 209–211; metamorphic, 208, 213–214; sedimentary, 207, 212–213; weathering of, 214–216
Root hairs, 516–517
Roots, 515–520; absorption of minerals, 516–518; as food, 539–540; cross section of, 516; functions of, 515, 518–520; osmosis, 517–518; structure of, 516
Rotation, of earth, 190–192; of planets, 168–173
Rubber goods, 260; manufacture of, 545–546
Rusting of iron, 46
Safety, glass, 275; in the homes, 400; in the use of electric fuses, 458–459; on the highway, 401; prevention of accidents with electricity, 474–476
Saliva, 632
Salt, 213, 264–266; formation of, 264; in the sea, 265; need of, 264; useful to man, 265–266; where found, 264–265
Saprophyte, 552
Satellite, 174
Saturate, 89
School rooms, lighting of, 388
Scientific method, examples of, 1–9, 243–244
Scientists, contributions of, 8–9; early, 1; methods of working, 2–8
Sclerotic, 420
Screw, 327–328
Scurvy, 619–620
Sea breeze, 124
Seasons, ~~cause of~~, 194–196
Secretions, 642
Sedimentary rocks, 207, 212–213
Seeds, development of, 530–531; dispersal of, 531–532; germination of, 532–534; structure of, 533–534
Seismograph, 226
Semicircular canals, 65
Semi-direct lighting, 400–401
Sepals, 528
Septic tank, 79, 659
Sequoias, 520
Serum, 677
Sewage disposal, 79–81, 659
Shale, 212
Short circuit, 458–459
Silicon, 259; dioxide, 270
Silk, 544; cocoon, 598–599; manufacture of, 599; worm, 583, 598
Silver, bromide of, 265; used in photography, 413–414
Siphon, 29
Sirius, 181, 183
Skin, 654, 660–661
Sleet, 136, 149
Smallpox, control of, 6–7, 675–676
Smoke, prevention of, 350–351, 379–380, 500, 513
Smoking, 666–667
Snakes, 592–593; poisonous, 593
Snow, 135, 149
Soap, in hard water, 76; manufacture of, 262–263, 264, 543

Sodium, 259; chloride of, 264; hydroxide of, 263–264
Soil, 228–247; composition of, 228–230; conservation of, 237–245, 515, 518–520; cultivation of, 231–233; drainage of, 233–234; irrigation of, 234–237; kinds of, 229–230; plant food in, 237–244, 515; water in, 230–231
Soil conservation, 237–245, 515, 518–520
Soil water, 230
Solar system, 156–189
Solutions, 89–90; for electroplating, 470–471; for electrotyping, 471; freezing point of, 356; properties of, 90; saturated, 89, 251, 262; solute, 89; solvent, 89; suspensions, 89; tincture, 89
Sound, 50–67; in a vacuum, 51; motion pictures, 62–63; musical tones, 58–61; produced by phonograph, 61–62; produced by voice, 63; production of, 51–53; reflection of, 57; speed of, 55; to measure ocean depths, 58; transmission in air, 51; transmission in water, wood, and iron, 56; waves, 53–55, 482
Soundproof material, 57, (new), 492
Sound track, 63
Specific gravity, 110, 472–473
Spectroscope, 159–161, 171
Spectrum, 159; complete, 405; solar, 416, 419
Spiders, 585–586
Spinal cord, 645–646
Spirogyra, 550–551
Sponges, 575, 658–659
Spores, 549
Spring, season, 195; temperature of soil in, 231
Spring tides, 180
Springs, 70, 219–220
Stainless steel, 267, 271
Stalactites, 221
Stalagmites, 221
Stamen, 528
Standard time, 199–201
Starfish, food of, 578
Stars, 181–187; brightest star, 183; constellations, 184–185; distance from earth, 181–182; nebula, 183; number of, 182; size of, 181–182; the north star, 182–187
Steam engine, effect on industry, 299–300; parts of, 298; principle of, 298–299
Steam power, 296–301; engines, 298–300; turbines, 300–301
Steel, 270–271; Bessemer converter, 270; kinds of, 271; open-hearth furnace, 270–271
Stem of cornstalk, cross section of, 525
Stems, 520–525; a living tower, 520; annual rings of growth, 522–523; as food, 539; bark, 524; cross sections of, 521, 525; functions of, 520; growth of, 522–525; structure of, 521–522, 524–525
Stigma, 528–529
Stimulant, 664–665
Stimuli, 571
Stirrup, 64
Stomach, 261
Stomata, 512–513
Stone Age, 316–317
Storms, 141–147; anticyclones, 143–144; cyclones, 141–143; hurricanes, 146; thunderstorms, 145; tornadoes, 147; typhoons, 146; warnings, 149
Stratified rocks, 212
Stratosphere, flights, 12–13; temperature of, 13
Stratum, 212
Stratus clouds, 133–134
Streamline, 331–332
Style, 529
Submarine, 106–107, 500
Sucrose, 622
Sugar, purification of, 343, 613, 622–623
Sugar and starch, 514–515
Sulfur, as plant food, 238
Sun, 157–166; as protection against disease germs, 387; as source of heat, 337; as source of light, 387; brightness of, 164; composition of, 158–159; energy of, 164–166; layers of, 162–163; rotation of, 163; size of, 158; source of energy for photosynthesis, 514–515; spectrum of, 159–162; spots, 160, 163; temperature of, 164
Sunspots, 160, 163
Sun time, 199
Sundial, 199
Sunlight, 159–161
Sunshine and Vitamin D, 622–621
Surgery, 661–662; aseptic, 662
Suspension, 89
Synapse, 645
Synthetic rubber, 546

Tadpoles, 591
Tapeworm, 579

Tea, 664–665
Teeth, care of, 631–632, 663; function of, 631; need of exercise, 632
Telegraph, 5, 480–482
Telephone, 5; invention of, 482; operation of, 483–485; receiver, 483; systems, 482; transmitter, 483
Telescope, 4, 171, 172; lenses in, 413
Temperature, measurement of, 355–356; produced by electricity, 467–468; scales of, 355–358
Tennessee Valley, 242
Tension, 59
Textiles, artificial silk, 544; cotton, 542–543; from plants, 542; linen, 543–544; natural silk, 544; wool, 599
Theory, 2–8; early, of solar system, 3–5; of light, 403–404
Thermometer, 268; air, 359; centigrade, 356–358; Fahrenheit, 356–358
Thermos, bottle, 373–374; jug, 374
Thermostat, 361
Thorax, of insects, 582
Thunder, 145, 433
Thunderstorms, 145, 250, 431
Thyroid gland, 616
Tides, 177, 180
Timbre, 60
Time, 199–201; belts, 200–201; standard, 199–201; sun, 199; sundial, 199
Tincture, 89
Tissues, 509
Tobacco, effect on the body, 666–667
Tools, development of, 316–317; machines, 271; of early man, 1, 221–222; pneumatic, 34
Tooth, paste, 266; powder, 266
Tornadoes, 147
Torricelli, 15, 26
Toxin, 676
Transformers, 451–455; experiment with, 452; step-down, 453; step-up, 453; use of, 453–455
Translucent object, 392
Transmission, of heat by conduction, 369–370; of heat by convection, 370–372, 374–380; of heat by radiation, 372–373, 374–375; of heat in cooking, 374; of heat in fireplace, 374; of heat in heating systems, 375–379; of light, 390–392, 403–404; of sound, 51–58
Transparent object, 392
Transportation, by electricity, 497–501; improved by science, 8–9; in air, 19–22; in stratosphere, 13
Troposphere, 13
Tuber, 539
Tuberculosis, 387; in prehistoric man, 658; resistance to, 674–675
Tungsten, lamp, 398; steel, 271
Tuning fork, 52–54
Turbines, 295–296; steam, 300–301, 500; to generate electricity, 450, 454–455; water, 295–296
Turtles, 592–593
Typhoid, and drinking water, 80, 675
Typhoons, 146
Typhus, 387, 571

Ultra-violet, rays, 404–405
Umbra, 392
United States Weather Bureau, 147; service of, 147–151, 356

Vaccination, for smallpox, 7, 675–676
Vaccine, 676
Vacuum, bottle, 373–374; defined, 16; partial, 24–25; tube, 488–489
Vacuum cleaner, 30–31
Valves, expansion, 95–96; in gasoline engine, 302–303; in pumps, 27–29; in steam engine, 298
Vaporization, 90; heat of, 366–367
Vapor-vacuum heating system, 379
Veins, of leaf, 511–512, 638–640
Ventilation, 380–382
Vertebrates, 588–597
Vibration, irregular, 59, 61–65; regular, 59; to produce sound, 52–53
Villi, 635
Vinegar, 261–262
Vitamins, 617–622; effects of deficiency of, 618–622; in leafy foods, 537–538; sources of, 617–622; table of, 628
Vocal cords, 63
Voice, 63; effect of cold, 63
Volcanoes, 222–223; active, 223; crater, 223, 278; dormant, 223; extinct, 223
Volt, defined, 437, 456
Voltmeter, 437
Voltaic cell, 433–435

Washing soda, 266
Water, 68–114; buoyant force of, 105; composition of, 85–86; density and specific gravity of, 107–109; electrolysis of, 84–85; floating bodies, 105–107; for plant growth, 228–237, 257; from burning kerosene, 395; hard and soft, 75–76; hydraulic

Water—(*Continued*)
brakes, 104; hydraulic press, 103–104; in soil formation, 217–222; measure of pressure, 99–102; meter, 81–82; purification of, by boiling, 75; by distillation, 75; by filtration, 73–74; by use of alum, 72–73; by use of ammonia, 75; by use of chlorine, 75; solutions of, 89–90; sources of drinking, 69–71; systems, 77–78; vaporization and condensation, 90–91
Water wheels, 294–296; overshot, 294; Pelton, 295; turbine, 295–296; undershot, 294–295; to generate electricity, 454–455
Waterspout, 147
Watt, 455–458
Waves, electromagnetic, 405; frequency of light, 407; light, 404–405; lengths of, 418; photograph of sound, 55; radio, 404–405, 487; sound, 53–55; compressed layer of, 53; rare layer of, 53, 482; water, 54; amplitude, crest, frequency, length, trough of, 54–55
Weather, 115–155; and growth of plants, 515; clouds, 129–134; dew, 129; effect on clothing, 118; effect on shelter, 118; effect on work, 119–120; effect upon food supply, 116–117; forecasting, 147–151; frost, 129; humidity, 126–128; rainfall, 134–137; storms, 137–147
Weather map, 150; "High," 149; "Low," 149
Weathering, 214–216; today, 219, 229
Wedge, 328
Weeds, 231–232
Weight, 290; and machines, 318–328; units of, 313
Welsback mantle, 397
Wheel and axle, 324–326
White corpuscles, 636
Winds, 137–141; antitrade winds, 140; doldrums, 140; monsoons, 139–140; prevailing westerlies, 141; trade winds, 140, 209, 215
Wireless telegraphy, 496
Wool, 599
Work, 293–307; and power, 314–315; defined, 312–313; measurement of, 313–314

X-Rays, 404–405, 473–474

Year, 191
Yeast, 42, 559
Yellow fever, carried by mosquito, 7, 671

Zinc, 267; oxide, 260, 267

40

Date Due

EDUCATION LIBRARY

EDUCATION LIBR

Lake

Q
161
.L19

COMPACT STORAGE

120684

CURRICULUM

EDUCATION LIBRARY

Q 161 L19 c.1
Lake, Charles H. (Charles
Exploring the world of science
EDUC
0 0004 8499 768

A9846